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BIRD IMPACT RESISTANT ANALYSIS OF  
THE F-15E PRODUCTION TRANSPARENCY SYSTEM



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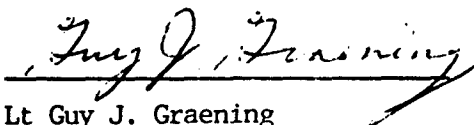
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13. ABSTRACT (Maximum 200 words) <p>The F-15E production transparency system was tested for its ability to withstand bird impact during simulated low altitude missions. The system consisted of the monolithic stretched acrylic windshield and two-piece canopy. An F-15B test fuselage was modified to an F-15E configuration with a wide field-of-view Head Up Display (HUD) and an inert ACESII ejection system. The low altitude mission was simulated by impacting a stationary fuselage pitched at two degrees angle of attack.</p> <p>Five tests were conducted in which bird velocity, weight, and impact location were varied to determine transparency system response and crew survivability. The impact locations consisted of the center high quarter point for the windshield and the low center point for the canopy. Test 1 provided a baseline for acquiring deflection data with a 4-pound impact to the windshield at 426 knots; the transparency system remained structurally intact. The HUD was installed for Test 2 in which a 4-pound bird impacted the windshield at 427 knots; the windshield contacted the HUD combiner glass resulting in catastrophic structural failure of the acrylic panel. A second HUD was installed for Test 3 in which a 4-pound bird</p>				
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impacted the windshield at 395 knots; the windshield contacted the HUD combiner glass but remained structurally intact. The canopy was impacted in Test 4 with a 4-pound bird at 496 knots; the canopy failed, the bird penetrated, and the witness plates sustained damage. Test 5 impacted the windshield with a 2-pound bird at 536 knots; the transparency system remained structurally intact.

The test results should be incorporated into a risk analysis to quantify the bird impact threat to the F-15E fleet. The transparency deflection and strain data acquired during the testing can validate finite element models used to explore alternative F-15 transparency systems.

## FOREWORD

The work documented in this report is part of the F-15 Advanced Transparency Program conducted by the Windshield Program Office under Program Element 64212F, Project Number 1926. The program objective is to demonstrate and transition transparency technology solutions that reduce flight safety risks and supportability costs to meet the F-15 mission requirements up to and beyond 2000. The initial phase of the program investigates the characteristics of the production F-15 transparency system such as change-out time, maintenance procedures, service life, optics, and bird impact resistance. The results of the bird impact testing covered in this report will provide baseline data from which future F-15 transparency systems can be demonstrated in subsequent program phases.

The testing was performed by the Arnold Engineering Development Center (AEDC), Arnold Air Force Base during the period 28 May through 15 November 1991. The Project Engineer for the testing was 2Lt Guy J. Graening of Wright Laboratory, WL/FIVR, Flight Dynamics Directorate, Wright-Patterson Air Force Base. Technical operations were conducted at the Bird Impact Test Unit (Range S3) of the Von Karman Gas Dynamics Facility by Mr Wayne Jennings, CALSPAN. Air Force administrative direction was provided by Mr Rick Rushing, AEDC/DOFR. Technical drawings included in this report were created by Ms Teresa Williams, WL/DORG.

The Windshield Program Office would like to acknowledge the following program team members who made the testing possible: Mr John Hutson and Capt Ralph Urch of the F-15 System Program Office, Mr Hugh Darsey and Mr Jimmy Andrews of Warner-Robins Air Logistics Center, Lt Col Bruce Thompson and Maj John Marshall of Headquarters Tactical Air Command, Mr Lee Clanton and Mr Ed Kuch of the 3246th Test Wing, Mr Dan Bowman of University of Dayton Research Institute, Mr John Lankford and Mr Brian Faust of McDonnell Douglas Corporation.

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## 1.0 INTRODUCTION

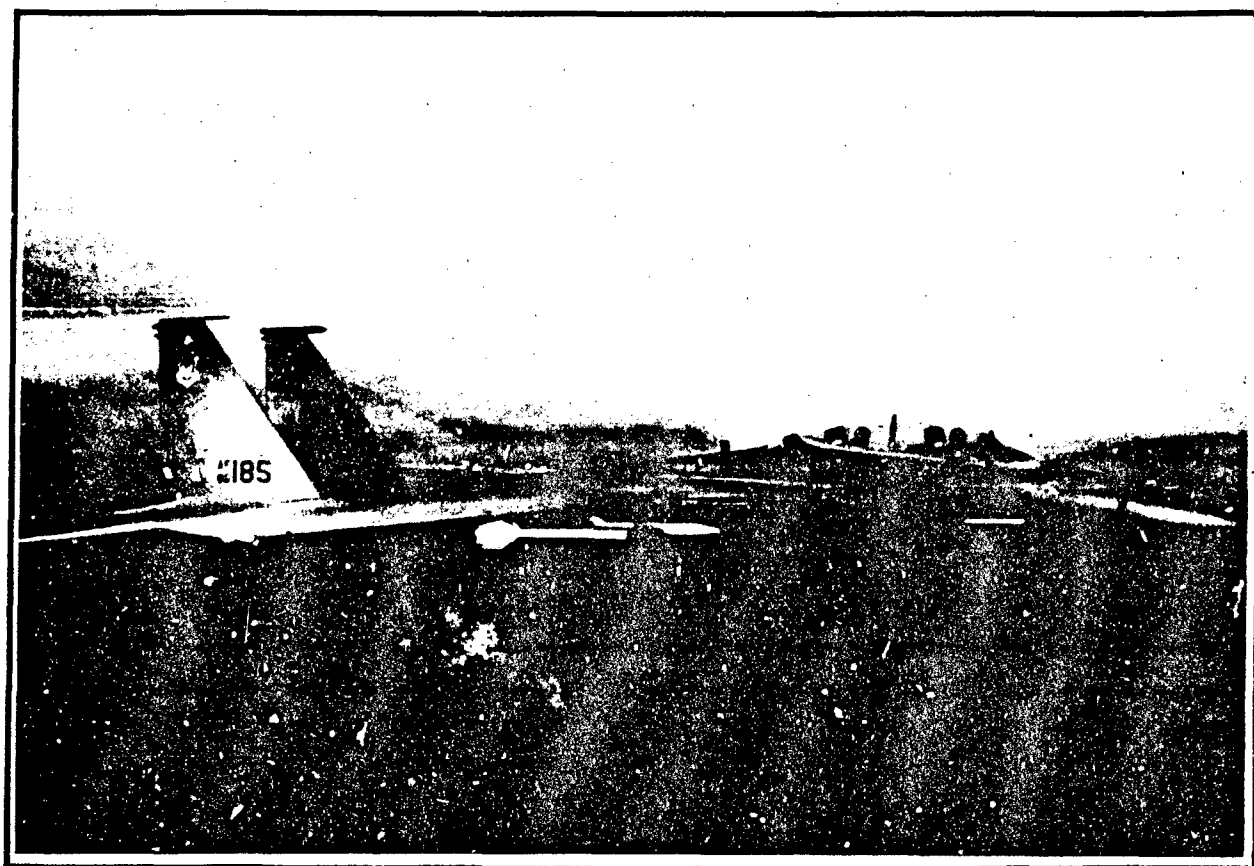
Bird impact testing is conducted on windshields, canopies, and other aircraft components to design systems that will protect the lives of aircrew when they fly in the bird environment, an altitude range from 0 to 5000 feet above ground level. Bird impact testing not only determines the capability of current systems but also provides data critical to the design of future bird resistant transparency systems. The testing described in this report investigated the bird impact resistance of the F-15E transparency system and provided data required for future F-15 transparency technology development.

1.1 Background The F-15 Eagle originated as an air superiority fighter in the early 1970's. The Eagle's transparency system required minimal bird impact resistance to safely conduct the air superiority mission. The system incorporated a fixed windshield and a moveable canopy. The windshield was composed of a 0.90 inch monolithic stretched acrylic panel bolted into an aluminum frame. The bird impact resistance of the windshield was determined to be between 353 and 385 knots during birdstrike tests conducted in 1977 (Reference 1).

The canopy was similar in cross-sectional design with a forward and an aft 0.335 inch monolithic stretched acrylic panel. The only birdstrike test data available to date on the canopy comes from early developmental testing on the TF-15 two place trainer aircraft (Reference 1). The canopy testing was conducted in 1977 by McDonnell Douglas Corporation and demonstrated 4-pound bird impact resistance of 160 knots at the low center. A 4-pound bird penetrated the canopy at 182 knots.

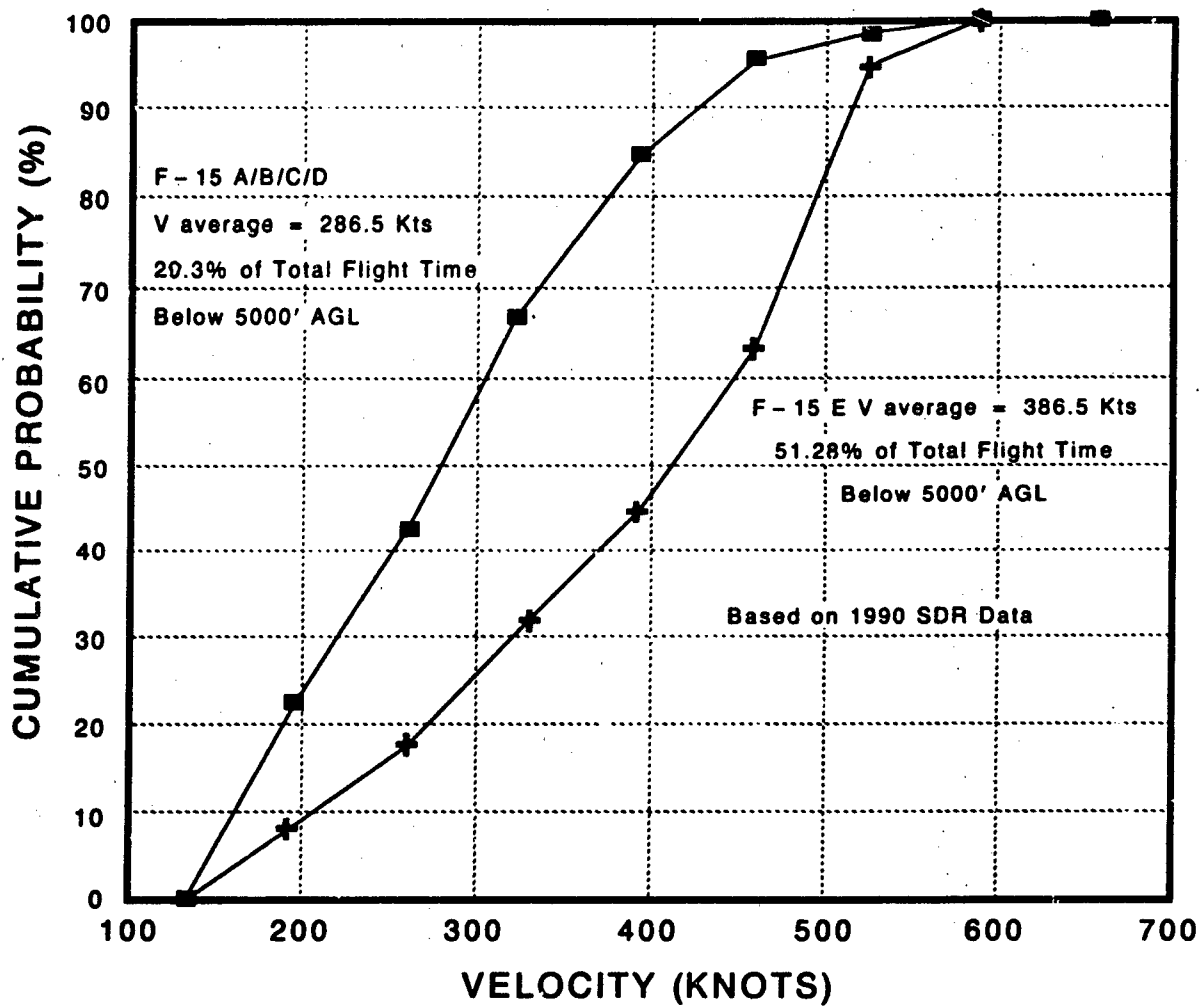
The latest variant of the fighter, the F-15E Strike Eagle, was developed to perform the air-to-ground mission in addition to the air superiority mission (Figure 1). The new mission requires the aircraft to spend over half of its flight time in the bird environment (Figure 2). Increased performance engines enable the F-15E to fly at sustained speeds in excess of 500 knots. These new mission conditions increase the probability of bird impact to exposed components of the F-15E aircraft, including its transparency system.

During the development of the F-15E, a bird impact resistance design goal was established for the transparency system to reduce the probability of serious pilot injury and aircraft loss. The goal was to provide protection from a 4-pound bird impact at the center and at the high quarter of the windshield for velocities of 500 and 450 knots, respectively. A bird impact resistance design goal was not established for the canopy.



**FIGURE 1**

**F-15E STRIKE EAGLE**



**FIGURE 2**

## **F-15 FLIGHT PROFILE IN THE BIRD ENVIRONMENT**

A windshield development program was conducted in 1983 by the F-15 System Program Office to provide data for the design of an improved birdstrike resistant windshield for the F-15E (Reference 2). The effort resulted in the selection of a 0.94 inch monolithic stretched acrylic windshield bonded into a titanium c-channel aft arch and an aluminum frame. The design was a thickened version of the earlier windshield with a new edge attachment system.

**1.2 Qualification Testing** Bird impact qualification testing of the selected transparency design was limited to the windshield only. The testing was conducted in 1987 by the prime contractor, McDonnell Douglas Corporation (Reference 3). The windshield demonstrated 4-pound bird impact resistance of 449 knots at the center and 435 knots at the high quarter. The testing resulted in selection of the design for production with a revision of the requirements for windshield thickness and tolerance from  $0.940 + 0.025 - 0.040$  to  $0.950 \pm 0.025$  inch. The 4-pound bird impact design goals of 500 knots at the center and 450 knots at the high quarter were predicted to be achieved by a windshield with the revised thickness tolerance using a finite element model strain analysis (Reference 3).

A bird impact resistance goal was not established for the canopy, and the same 0.335 inch monolithic stretched acrylic canopy used on F-15B and D models was selected to complete the production F-15E transparency system. The canopy thickness requirement of  $0.335 + 0.095 - 0.020$  inch was not changed for the F-15E model.

**1.3 Safety Concerns** The configuration used for the windshield qualification testing and the absence of additional canopy testing raised safety concerns regarding the bird impact resistance of the F-15E production transparency system.

The first concern was that the presence of the Head Up Display (HUD) could reduce the bird impact resistance of the windshield demonstrated in the qualification testing. The F-15E HUD incorporates a wide field-of-view combiner glass with a clearance between 0.82 and 0.94 inch from the inner surface of the windshield. The HUD was not present during birdstrike Test Q3 of the qualification testing in which the windshield deflection in the HUD area was 1.24 inches (Reference 3). The resulting 0.3 inch interference at the HUD could be enough to initiate failure of the acrylic panel, thus reducing the 435 knot birdstrike resistance demonstrated at the windshield center high quarter point.

The second concern was that the F-15E will operate at speeds in excess of 500 knots in the bird environment with a canopy that has roughly 170 knots of birdstrike protection. Although penetration of a 4-pound bird was expected at speeds above 170 knots, the extent of pilot injury had not been investigated for a canopy strike at mission speeds. The probability of a canopy

strike is critical for the F-15E because the canopy comprises 44 percent of the total frontal area of the transparency system at zero degrees angle of attack.

The last concern was that a small bird might be more critical than the standard 4-pound test bird. The aircraft transparency community has been investigating the effect of small bird (1 kilogram/2.2 pounds) impact at high mission speeds (more than 500 knots). The reduced cross-sectional area of the small bird concentrates the force of the impact on the windshield. Though the kinetic energy may be comparable to a 4-pound bird impact, the concentrated energy of the small bird might initiate a different failure mechanism (i.e. shear failure). This "feathered bullet" phenomenon seems to apply especially to monolithic acrylic configurations such as that found on the F-15E aircraft.

1.4 Test Objectives The safety concerns regarding the F-15E production transparency system and the need for developmental test data have prompted the additional testing described in this report. The objectives of the testing were to:

(1) Establish a test configuration that simulates low altitude mission conditions.

(2) Determine the bird impact resistance of the combined windshield/HUD system.

(3) Investigate the crew survivability during a high speed bird impact to the canopy.

(4) Study the effect of small bird/high speed impact on the windshield.

(5) Acquire strain and transparency deflection data during bird impact to validate future analytical models.

## 2.0 TEST CONFIGURATION

To achieve the objectives mentioned previously, air cannon impact testing was selected using full-scale test articles. Sub-scale coupon testing was eliminated as an option because of the complexity of structural interaction required in Objectives (2) and (3). Dynamic sled testing was eliminated as well to minimize cost and safety risks associated with the testing.

Air cannon impact testing simulates the birdstrike event by launching a bird at a stationary aircraft mockup. The "bird" can be either a gel bag or an asphyxiated chicken carcass. The mockup consists of an F-15B forward fuselage upgraded to an F-15E configuration. The impact speed of the bird was controlled to simulate the desired mission speed. The fuselage was positioned relative to the bird path not only to achieve the desired impact location, but also to simulate the desired attitude of the aircraft during a low altitude mission.

The F-15E production transparency system, or test article, was mounted on the test fuselage and placed in the test cell with various data acquisition systems. The bird impact facility housed an air cannon that accelerated the bird package toward the test article. A detailed description of the test configuration is given below.

**2.1 Test Article** The test article was comprised of the production windshield, PN 68A350016-1001, and canopy, PN 68A350010-1009, manufactured by McDonnell Douglas Corporation (Figure 3). A monolithic stretched acrylic windshield panel, supplied by Swedlow Incorporated, was bonded into a titanium and aluminum frame with PR 1725 polysulfide sealant. The impact locations selected for the testing consisted of the windshield center, high quarter point and the canopy low center point (Figure 4a).

Before each test, the thickness of the acrylic panel was measured to ensure it was within the required tolerance. An ultrasonic thickness measurement instrument provided the most accurate result without degrading the acrylic. The locations at which measurements were taken on each test article as well as the corresponding thickness values are found in Figure 4b.

**2.2 Test Fuselage** The test series utilized the F-15 Forward Fuselage Structural Assembly that was upgraded from an F-15B to an F-15E configuration (Figure 3). A wide field-of-view HUD and an inert ACESII ejection system was installed. The HUD was mounted on the production support structure to position the combiner glass relative to the windshield in the location shown in Figure 5.

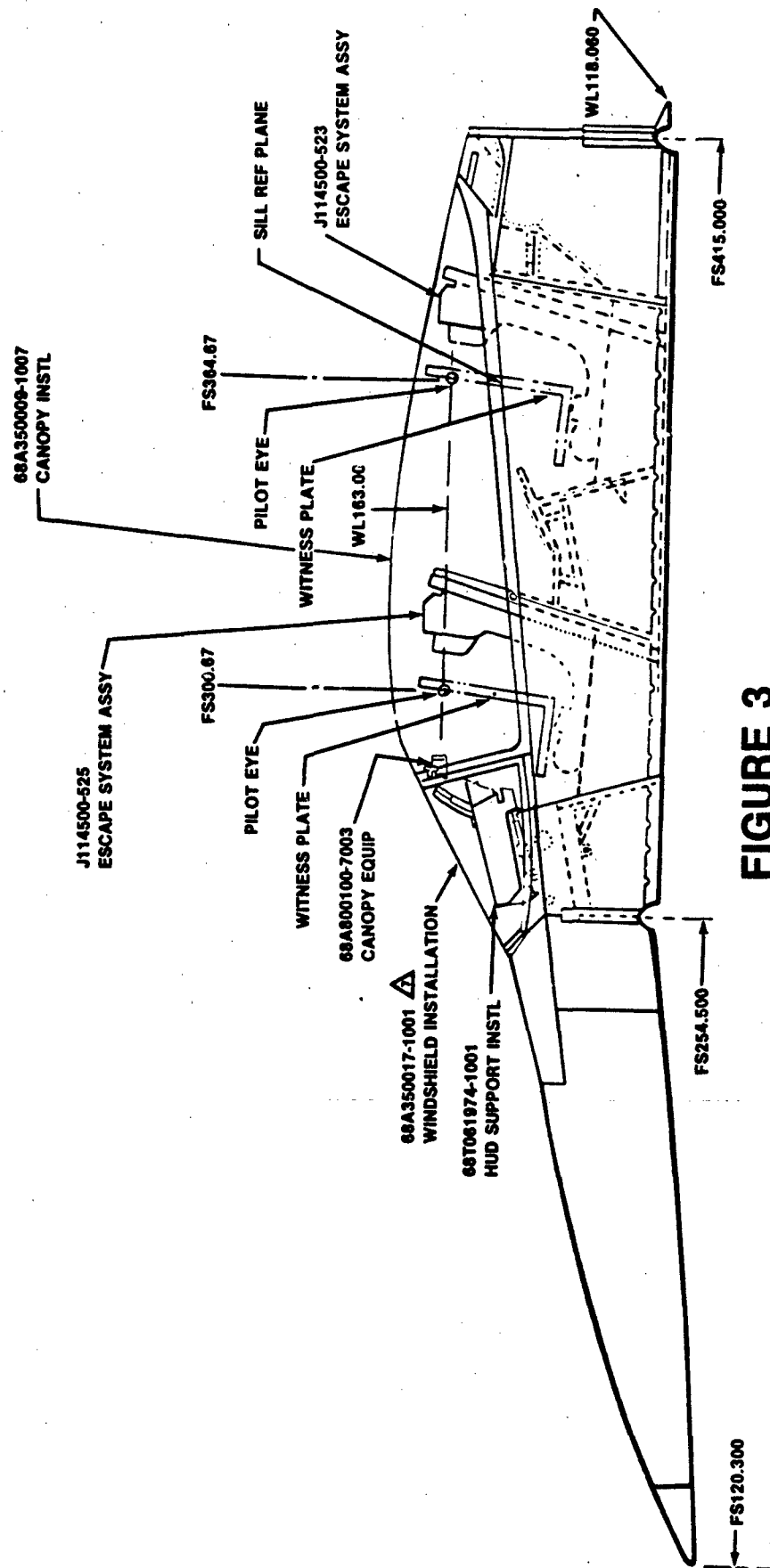
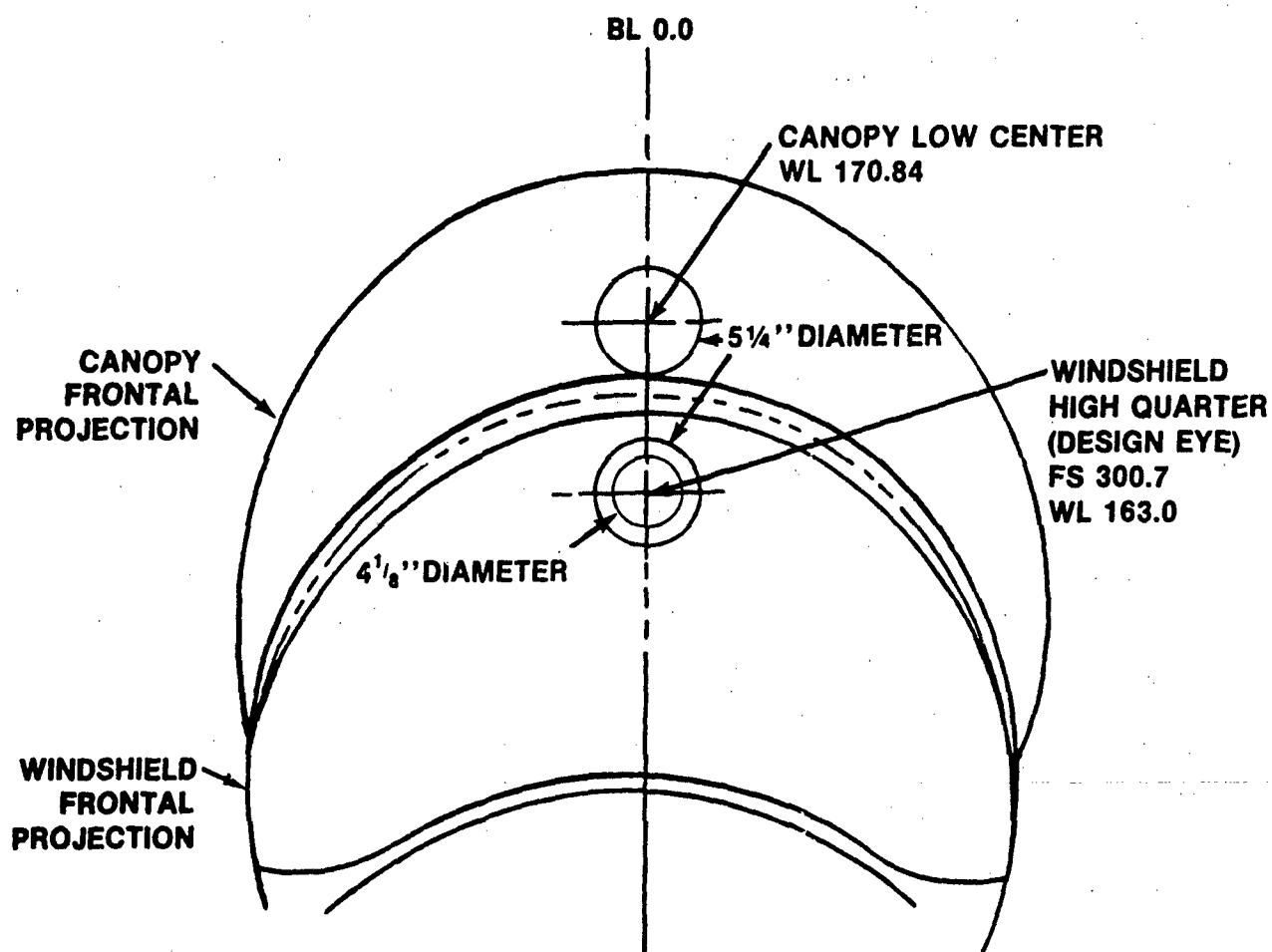


FIGURE 3

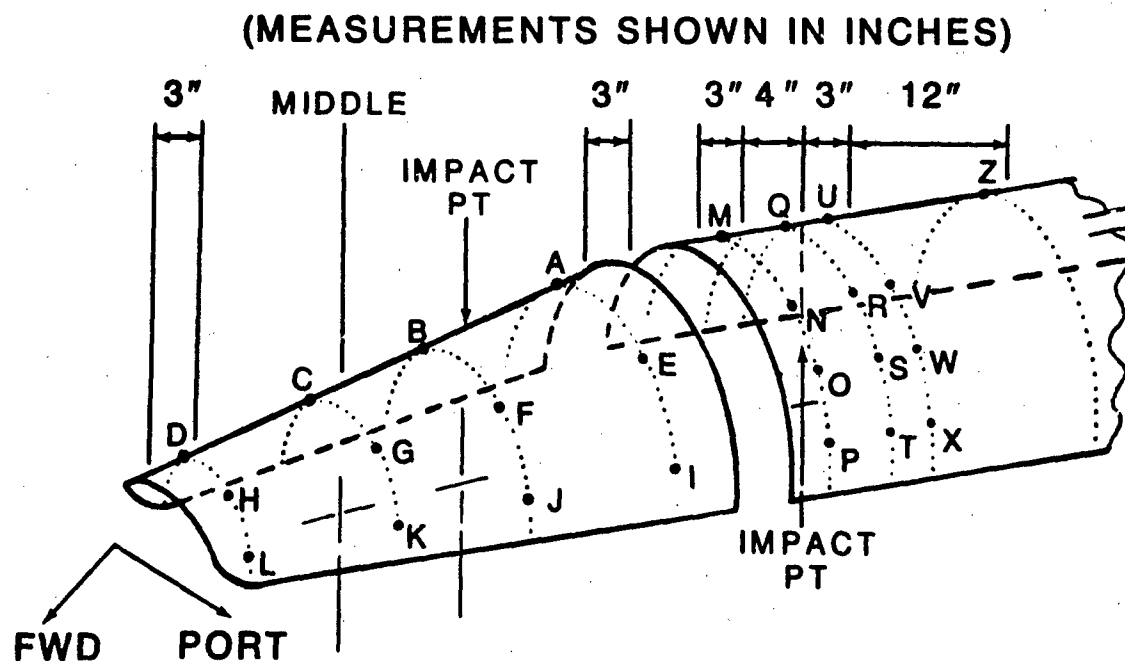
# F-15 TEST FUSELAGE

**4 LB BIRD —  $5\frac{1}{4}$ " DIAMETER**  
**2 LB BIRD —  $4\frac{1}{8}$ " DIAMETER**



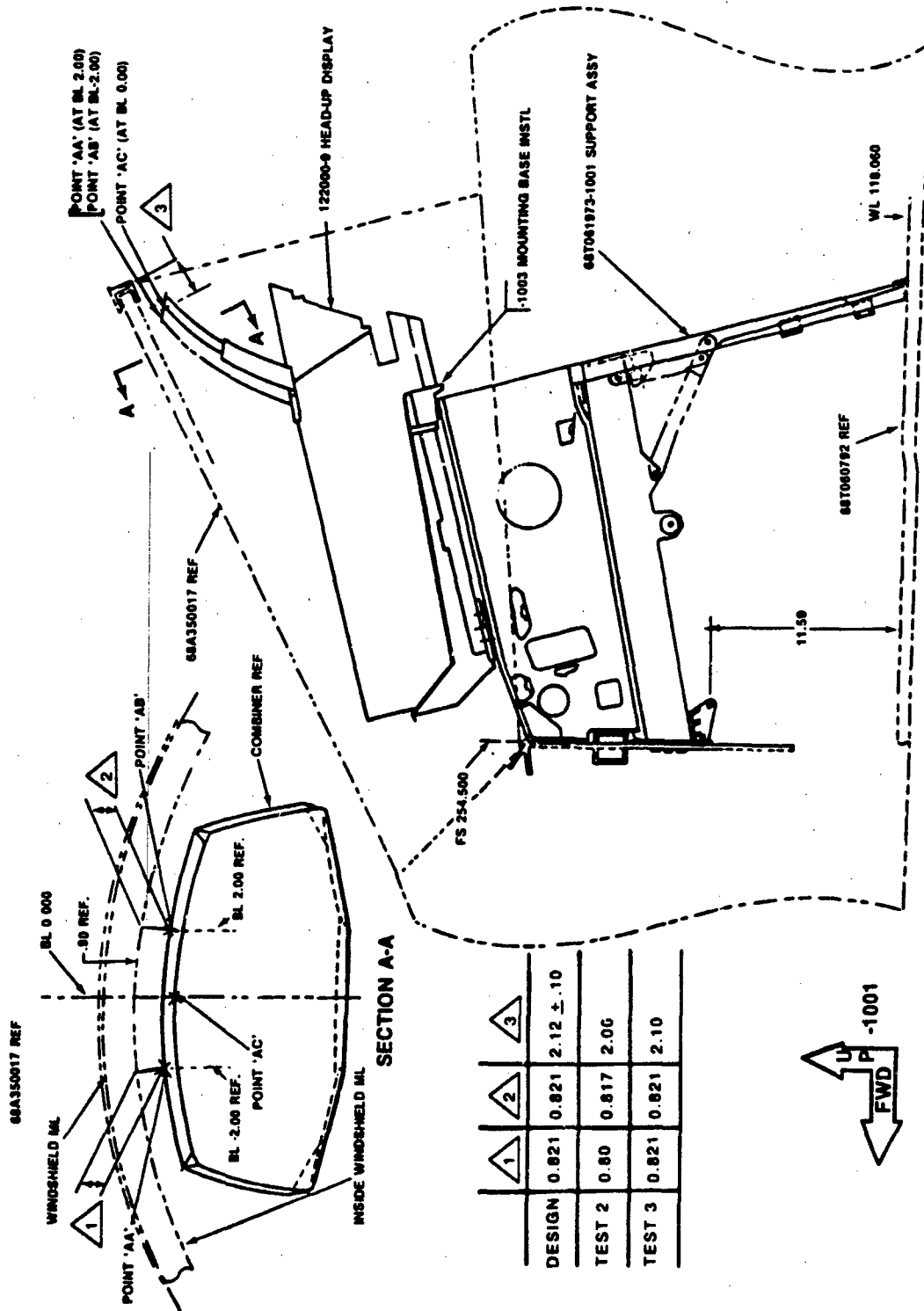
**2.0° ANGLE OF ATTACK  
VIEW LOOKING AFT**

**FIGURE 4A**  
**IMPACT LOCATIONS**



WINDSHIELD					CANOPY	
TEST #					TEST #	
	1	2	3	5		4
A	0.948	0.951	0.946	0.942	M	0.384
B	-	0.948	0.946	0.943	N	0.383
C	0.947	0.948	0.944	0.941	O	0.387
D	0.947	0.950	0.943	0.939	P	0.387
E	0.950	0.951	0.947	0.941	Q	0.367
F	0.950	0.948	0.947	0.940	R	0.364
G	-	-	0.947	0.940	S	0.377
H	-	0.950	0.947	0.940	T	0.386
I	0.950	0.957	0.948	0.942	U	0.355
J	0.950	0.945	0.949	0.942	V	0.355
K	0.949	-	0.947	0.941	W	0.372
L	-	0.946	0.947	0.941	X	0.385
					Z	0.341

FIGURE 4B  
MEASUREMENT LOCATIONS  
AND THICKNESS VALUES



**FIGURE 5**  
**COMBINER GLASS**  
**CLEARANCES**

The ACESII ejection system was included because it could affect both the response of the canopy during bird impact and the survivability of the aft crew member. A modification to the ACESII seat used on the F-15 includes a breaker bar that enables a crew member to eject through the acrylic canopy panel. The bar is mounted above the seat headrest and features a cutter in the center that will pierce the acrylic during ejection. The proximity of the cutter to the inner moldline of the canopy could cause interference during bird impact. Canopy contact with the cutter could initiate cracking of the monolithic acrylic, affecting the bird impact resistance of the transparency system. Additionally, the presence of the forward ejection seat could shield the aft crew member from any debris, thus influencing crew survivability.

The seat assembly was positioned in the cockpit to correlate with the size of the pilot selected for each test configuration. The configuration of the simulated aircrew is discussed in more detail in Section 2.5. The distance between the cutter and the inner moldline of the canopy was measured in inches for both seats before each test. The values are recorded in Figure 12.

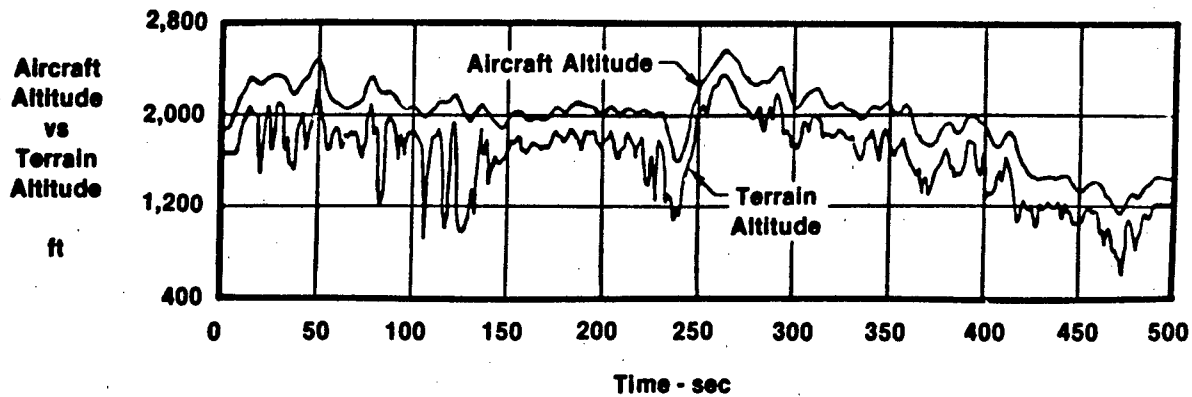
To simulate the attitude of the F-15E during a low altitude mission, the test fuselage was pitched nose up two degrees with respect to the bird flight path. The angle of attack (AOA) of the F-15E aircraft varies considerably throughout a mission (Figure 6). Two degrees represents a conservative AOA during a low altitude mission.

Note that the two degree AOA attitude of the fuselage changes the slope of the windshield relative to the flight path of the bird. For the F-15E fuselage in a level configuration, zero degrees AOA, the slope of the windshield is 28 degrees. The windshield qualification testing and early canopy testing were conducted with this configuration. Pitching the test fuselage at two degrees AOA results in reducing the windshield slope to 26 degrees. This, in turn, reduces the normal component of momentum imparted to the windshield by the bird.

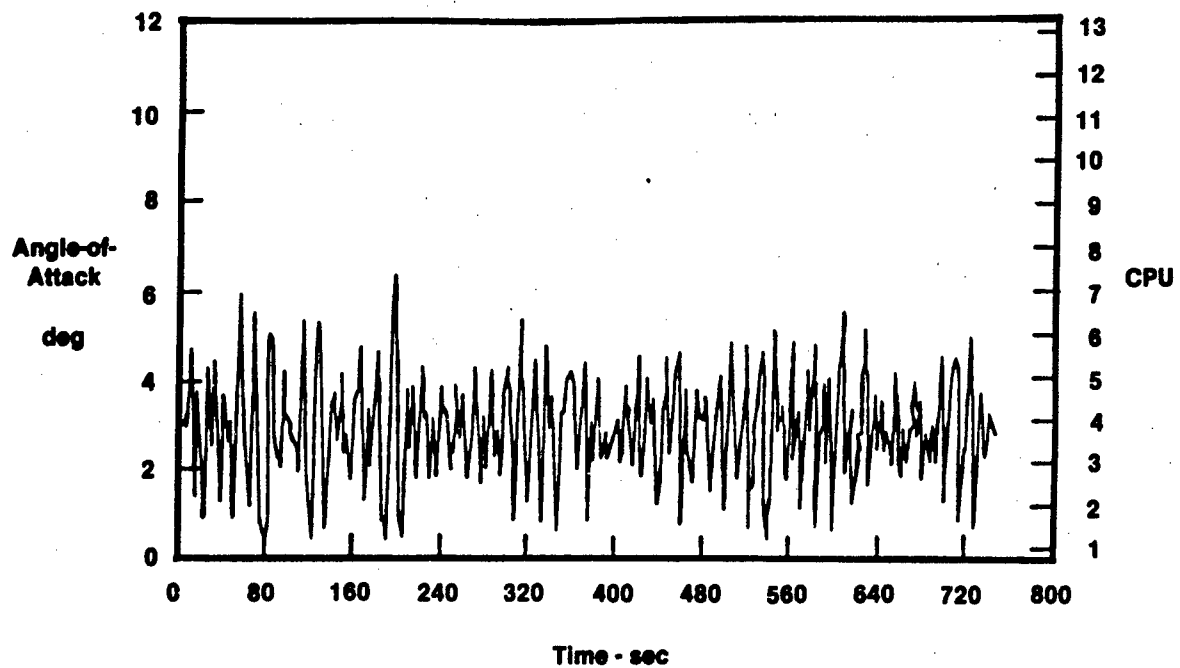
The windshield was installed according to TO-1F-15E-3-4, which allows the use of tacky tape to facilitate sealing. The canopy was rigged according to TO-1F-15E-2-95JG-21-2. The rain seal was installed and the main seal pressurized to 20 psi. The standby compass and rear view mirrors were installed on the canopy arch during Tests 3 and 4 to determine if they affect crew survivability by detaching and becoming projectiles.

**2.3 Bird Package** The bird package was a chicken carcass contained by a sabot illustrated in Figure 7. The bird was asphyxiated and stored at 0°F until needed. Before testing, the carcass was thawed in still air at room temperature for 24 hours until the body cavity was 60 +/- 5°F. To achieve the desired weight

## TYPICAL TERRAIN PROFILE

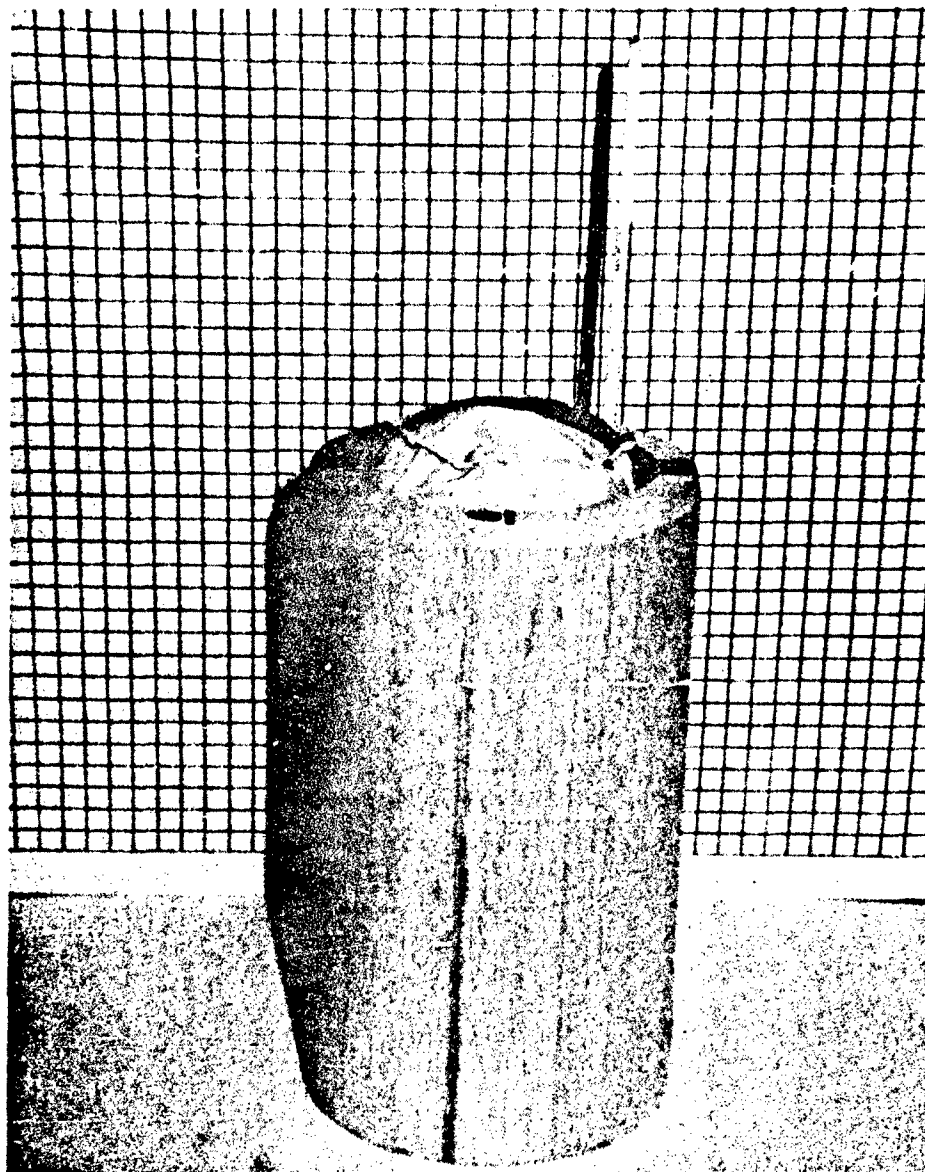


## ANGLE OF ATTACK



NOTE: MACH 0.9 ATF INGRESS ASD 4135 NORMAL MODE  
HD = 200 FT HARD RIDE

**FIGURE 6**  
**TYPICAL TERRAIN PROFILE / ANGLE OF ATTACK**



**FIGURE 7**

# **BIRD PACKAGE**

tolerance of  $\pm 0.1$  pound, minor weight adjustments were allowed by clipping appendages or by injecting water into the body cavity.

The bird was contained in a light nylon bag and placed in a balsa wood sabot with a nominal density of 11.4 pounds per cubic foot. The sabot confined the bird to a diameter of 5.25 inches for a 4-pound bird and 4.125 inches for a 2-pound bird as shown in Figure 4.

**2.4 Bird Impact Facility** The facility consisted of a fire control center, air cannon, and test area. The fire control center served as the focal point for the bird impact testing. The center housed the launch computer and recording devices associated with the data acquisition systems. A computer controlled the launch sequence that included charging the cannon, activating the data acquisition systems, and completing the firing circuit.

The air cannon was comprised of a driver tube, breech section, launch tube, vent section and stripper tube (Figure 8). The driver tube, a cylindrical 10.8 cubic foot reservoir, was charged with air compressed to 150 psi. The driver tube was mounted on guide rollers to allow opening of the breech section. The sabot containing the bird package was placed at a predetermined distance from the end of the launch tube. A mylar diaphragm separated the compressed air in the driver from the launch tube. Gas charged pistons activated a circular cutter that pierced the diaphragm. The sabot was accelerated down the 61 foot launch tube. The bird was separated from the sabot by a tapered and grooved stripper section at the end of the launch tube.

The test area was located at the end of the launch tube and housed the test fuselage and data acquisition systems (Figure 9). The test area structure consisted of a concrete pad (20 by 30 feet) for mounting the test fuselage, a blast wall to the rear, and a ceiling with a moveable hoist. Sliding doors on each side allowed for installation and removal of the test fuselage. To condition the ambient temperature in the test area to the desired  $75 \pm 15^\circ\text{F}$ , heaters or fans were activated several hours before the actual test.

**2.5 Data Acquisition Systems** Data was acquired during the testing using several systems: thermocouples, high speed cinematography, witness plates, still photography, and strain gages (Figure 10). Additionally, X-ray shadowgraphs and triangulation were used as part of the velocity and windshield deflection measurement systems (discussed in Sections 2.5.1 and 2.5.2). Thermocouples were placed near the test article to record ambient temperature for each test. These temperatures are listed in Figure 12. High speed cinematography provided dynamic visual coverage of each test for detailed post-analysis. Up to six cameras (Hycam 41-004 and FastaxII 46-0001) were operated at 5,000

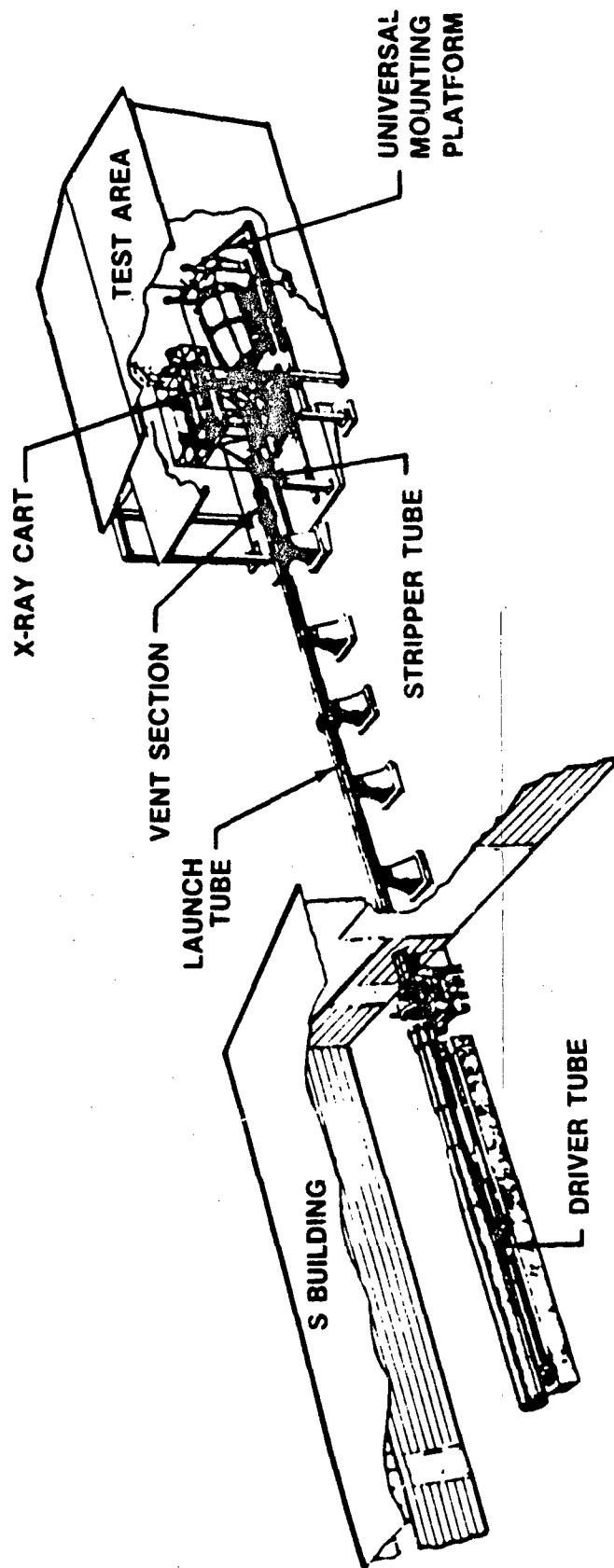


FIGURE 8

## BIRD IMPACT FACILITY



**FIGURE 9**

**TEST CELL**

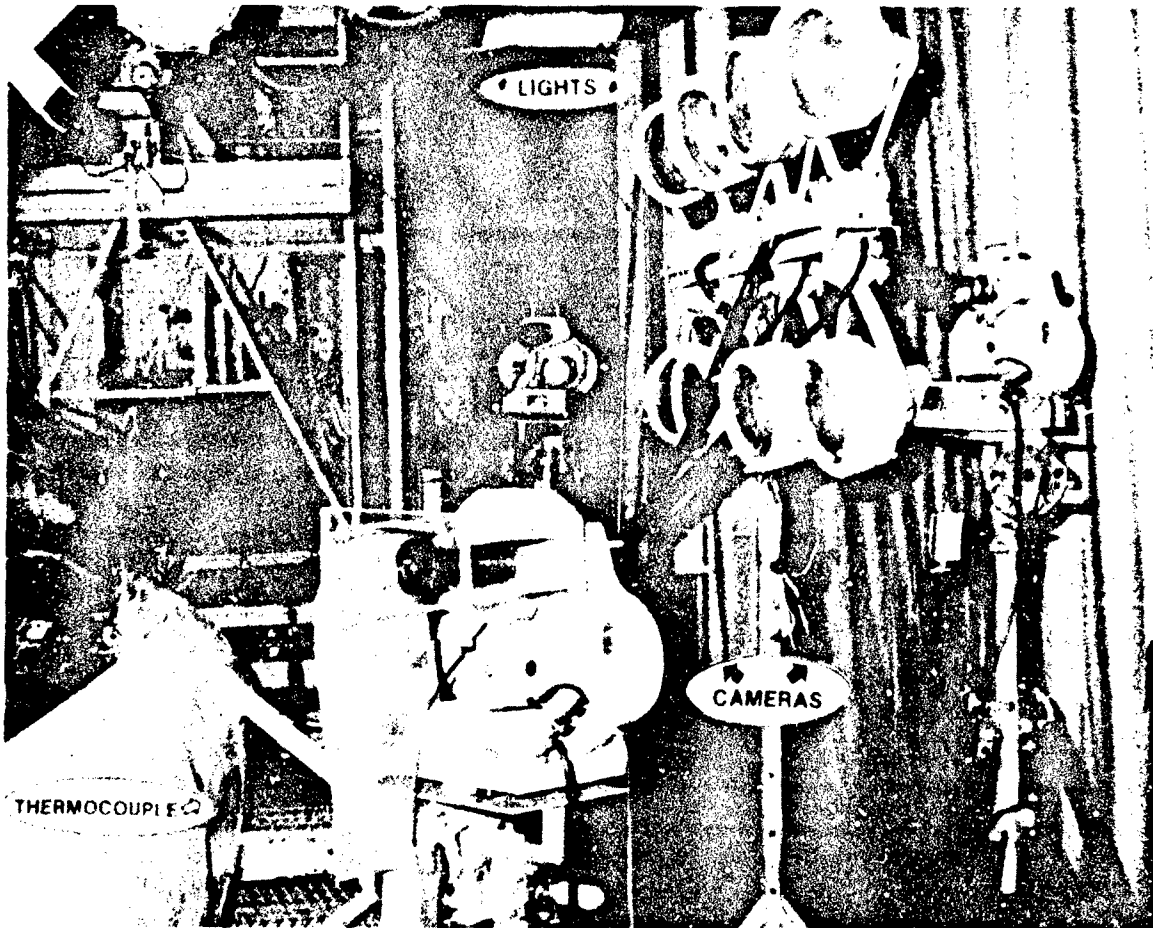


FIGURE 10

## DATA ACQUISITION SYSTEMS

frames per second with 400- and 100-foot rolls of 16-millimeter film. The cameras were used to record bird orientation, impact location, test article response, and damage to witness plates. Special camera functions were used in the triangulation deflection technique (refer to Section 2.5.2).

The high film speed of the cameras required intense lighting conditions. Twelve overhead floodlights, eight bank floodlights, and three interior spotlights were used to illuminate the exterior of the test fuselage as well as the interior surface of the test article (Figure 10). The lights were warmed for two seconds before the test with 110 volts, providing 1,000 watts per bulb. Just before the firing of the bird gun, the lights were boosted to 220 volts, providing 2,000 watts per bulb. The lights were positioned to minimize the reflected glare from the transparency system into the aperture of the cameras.

Witness plates were used to represent the aircrew seated in the cockpit and to determine the survivability for each birdstrike test. The plates simulated the position, profile, and composition of each crew member. The witness plates were positioned at the design eye locations of both the forward and aft crew stations illustrated in Figure 3. The profile of each crew member was based upon the dimensions of pilots of various percentile groups. Pilots of average height (50th percentile) were chosen for all tests except Test 4 where a specific configuration was selected (refer to Section 3.4). The composition of each crew member was roughly approximated by laminating a 0.032 inch aluminum sheet to a base of 2 inch of Styrofoam and 0.5 inch of plywood. The aluminum facing was painted white with a black cross at the design eye so that debris contacting the witness plate was visually apparent (Figure 11). The forward witness plate was modified to allow for placement of two cameras in the forward cockpit.

Strain gages were mounted on the aft arch of the windshield and on the supporting fuselage former directly beneath to record structural response and deformation during impact. Ten gages (Micro Measurements CEA-13-250UN-350) became an active leg of a bridge completion and signal conditioning system (Vishay Model 2120). The produced signals were recorded both on a digital transient recorder (La Croy 6810), and on a magnetic tape recorder (Bell and Howell VR3700B) as a backup system. The signals were converted into engineering units and plotted versus time. The locations on the test article and fuselage where strain was measured and the corresponding values are listed in Appendix A.

**2.5.1 Velocity Measurement** Impact velocity was determined using the X-ray velocity trap, comprised of three 105-kilovolt X-ray shadowgraph units and three digital chronographs (refer to Figure 9). The x-ray stations were 3.5 feet apart with the first station three feet from the end of the stripper section. A thin copper wire was stretched across each station directly in



**FIGURE 11**

**WITNESS PLATE**

the path of the bird during free flight. The bird broke the wire at each station, triggering an X-ray pulser and chronograph. The X-ray image of the bird was developed and a reference point on the chicken was selected. Distances between stations were refined by measuring from the reference point to the center of the X-ray image. Bird velocity was calculated by dividing the refined distance between stations by the time difference of consecutive chronographs. Bird velocity for each test is given in Figure 12.

A backup velocity measurement system was utilized that depended upon the camera placed perpendicular to the flight path. When the bird broke the third copper wire of the velocity trap, an event light in this side camera recorded a mark on the edge of the film. The number of frames was counted from the event marker to the frame showing the bird just touching the impact point on the test article. Dividing this number of frames by the film speed of the camera gives the time taken for the bird to travel the distance between the third station and the impact point. This distance was physically measured before each impact so that the bird velocity could then be determined.

**2.5.2 Windshield Deflection** The triangulation deflection technique was used to obtain a time history of windshield deflection during bird impact (Reference 4). This photographic approach used Pythagorean relationships to calculate the change in space position of points on the test article relative to defined pre-impact geometry.

The points of interest were marked on the inner surface of the windshield with white adhesive label tape made by Avery. A white cross with two black legs contrasted against both the white background of the chicken and the dark background created by the high speed of the film. The locations of the points were chosen to coincide with nodal points of an analytical model and are shown in Appendix B. The nodes indicated are on the inner moldline of the windshield and are given in aircraft coordinates when possible. Two cameras were mounted inside the test fuselage to capture these points of interest in a common field of view.

Special camera functions allowed frame by frame analysis of the bird impact event. The event marker made an instantaneous reference mark on the film in both inside cameras. This allowed the individual event frames to be synchronized. A 1000-Hertz timing light made similar marks on the opposite margin of the film so that the frame rate of the cameras could be determined.

Scale measurements of the deflecting points were obtained in a projected plane using a film analyzer. Knowing the magnification factor of each camera and the pre-impact geometry of the set-up, Pythagorean relationships were used to solve for changes of point position. Time histories of selected points for Tests 1, 2, 3, and 5 are included in Appendix B.

# CONFIGURATION SUMMARY

TEST	SHOT NO.	IMPACT VELOCITY (KNOTS)	BIRD WT (LBS)	IMPACT LOCATION	HUD	EJECTION SEATS		WITNESS PLATES		AMBIENT TEMP (°F)	STRAIN GUAGING	DATE 1991
						FWD	AFT	FWD	AFT			
1	1068	426	4.0	W/S	NO	YES 4.55	NO	50% MOD	50% FULL	72	NO	6 JUN
2	1069	427	4.0	W/S	YES	YES 4.55	NO	50% MOD	50% FULL	92	YES	11 JUL
3	1070	395	4.0	W/S	YES	YES 4.55	NO	50% MOD	50% FULL	74	YES	17 JUL
4	1079	496	4.0	CANOPY	NO	YES 6.88	YES 0.90	95% FULL	5% FULL	68	NO	24 SEP
5	1082	536	2.0	W/S	NO	YES 4.55	NO	50% MOD	50% FULL	63	NO	14 NOV

FIGURE 12

### 3.0 RESULTS

A total of five tests were conducted on the F-15E transparency system, utilizing four windshields, five forward canopies, and two HUD combiner glasses. The objective, configuration, and result of each test is described below. Refer to Figure 12 for a configuration summary of the tests.

The determination of whether a test was a "pass" or "fail" depended upon post-analysis of the test article, high speed film, and witness plates. For a test to have been considered a "pass", the test article must have remained structurally intact with little or no bird penetration. Additionally, debris resulting from the impact must not have damaged the witness plates. A test was a "fail" when there was excessive bird penetration or damage to the witness plates. If the outcome of any test in the series had not been readily discernable using the above criteria, the test participants agreed to formulate a mutual determination.

3.1 Test 1: Windshield/Baseline The objective of Test 1 was to provide a baseline for the test series using the configuration selected to simulate a low altitude mission. The lighting, photographic coverage, and other data acquisition systems were tested and adjusted. The absence of the HUD combiner glass provided the internal cameras with an undistorted view of the desired triangulation marks. This allowed deflection data to be gathered for post-test analysis. To determine if the 425 knot predicted velocity would cause the windshield to deflect in the area normally occupied by the combiner glass, a wire coat hanger was bent in the silhouette of the combiner glass and positioned in the same location near the windshield.

A 4-pound bird traveling at 426 knots impacted windshield S/N A41-0314 at the high quarter location. The impact resulted in the transparency system remaining structurally intact. Review of the high speed film confirmed that the windshield did contact the wire combiner glass silhouette during deflection. Post-inspection revealed scuff marks from the bird on the windshield and damage to the arch (Figure 13). The canopy arch and flange bent and cracked to absorb some energy of the deflecting windshield arch. The windshield arch separated enough from the canopy arch to allow several ounces of bird debris to enter the cockpit. Bird debris hit the forward camera, but both witness plates were unmarked. The bird scooped underneath the upper flange of the C-channel windshield arch and ripped a 10 inch section from the titanium arch. Test 1 was determined to be a "pass" after inspection of the test article and witness plates.

3.2 Test 2: Windshield/HUD Interference The objective of Test 2 was to determine how the presence of the HUD affects the response of the windshield during repeated conditions of Test 1.

# TEST 1: SCUFF MARK, ARCH DAMAGE

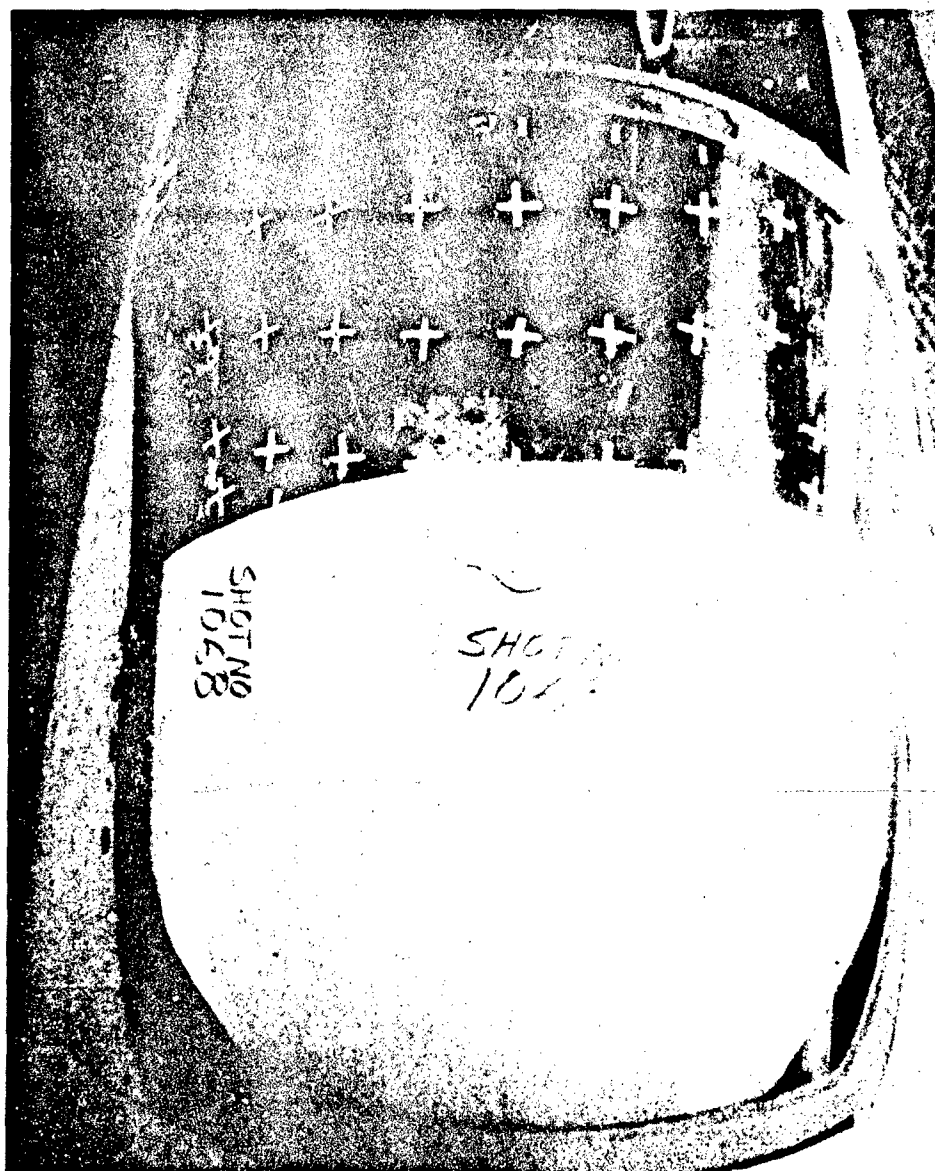


FIGURE 13

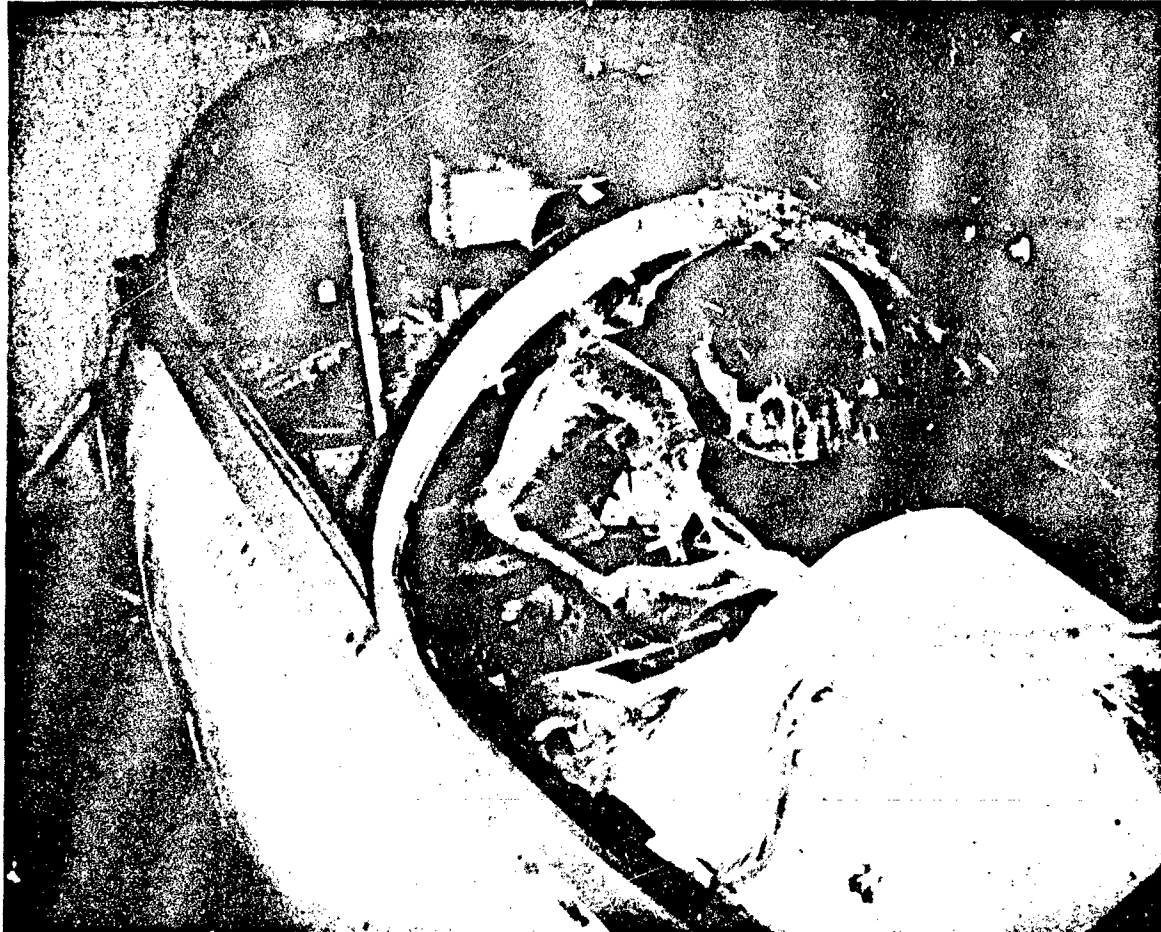
A HUD unit, including the combiner glass, a new windshield, S/N A41-0316, and a new canopy assembly were installed for Test 2. The canopy assembly from Test 1 was sent to Warner-Robins Air Logistics Center for repair.

A 4-pound bird impacted the windshield high quarter at 427 knots resulting in catastrophic structural failure (Figure 14). Review of the high speed film revealed that the failure was initiated when the windshield contacted the combiner glass. The contact cracked the monolithic acrylic panel and shattered the combiner glass inward. The windshield panel rebounded outward splintering pieces of acrylic, some as large as 18 by 6 inch. A post-inspection revealed that bird, acrylic, and glass debris impacted the forward camera (Figure 15). The witness plates were slightly scratched, but remained intact. The canopy transparency cracked, pressurization was lost in the seal, and the forward arch flange bent downward. Test 2 was determined to be a "fail" due to structural failure and bird penetration.

3.3 Test 3: Windshield/HUD Contact The objective of Test 3 was to determine the maximum impact speed that the combined windshield and HUD system could withstand. A new windshield, S/N A41-0323, canopy assembly, and HUD unit were installed for Test 3. Additionally, three mirrors and a standby compass were added to the forward canopy arch to determine if they would be a factor in crew survivability.

A 4-pound bird impacted the windshield high quarter location at 395 knots. The impact resulted in the transparency system remaining structurally intact. The windshield had scuff marks from the bird and sustained damage to the arch. The upper flange of the C-channel arch was peeled away from the acrylic (Figure 16). Review of the high speed film indicated that the windshield did contact the combiner glass, which oscillated after the impact. A post inspection revealed score marks on the inner windshield surface confirming that the HUD combiner glass contacted the windshield (Figure 17). Canopy seal pressurization was maintained. No bird debris penetrated the cockpit and the mirrors and compass remained intact. Test 3 was determined to be a "pass."

3.4 Test 4: Canopy/Penetration The objective of Test 4 was to investigate the crew survivability during a 500 knot impact with a four pound bird. A crew configuration was selected in which both crew members were positioned for maximum interference with the flight path of a penetrating bird. A tall forward crew member (95 percentile) would have more of his head exposed in the bird path than a shorter pilot. Additionally, the tall forward crew member would have his seat adjusted in the lowest position, providing the least shielding protection from debris headed toward the aft crew member. Similarly, a short aft crew member (5 percentile) was chosen because his seat would be adjusted in the highest position. This not only places his head in the bird path, but also places the



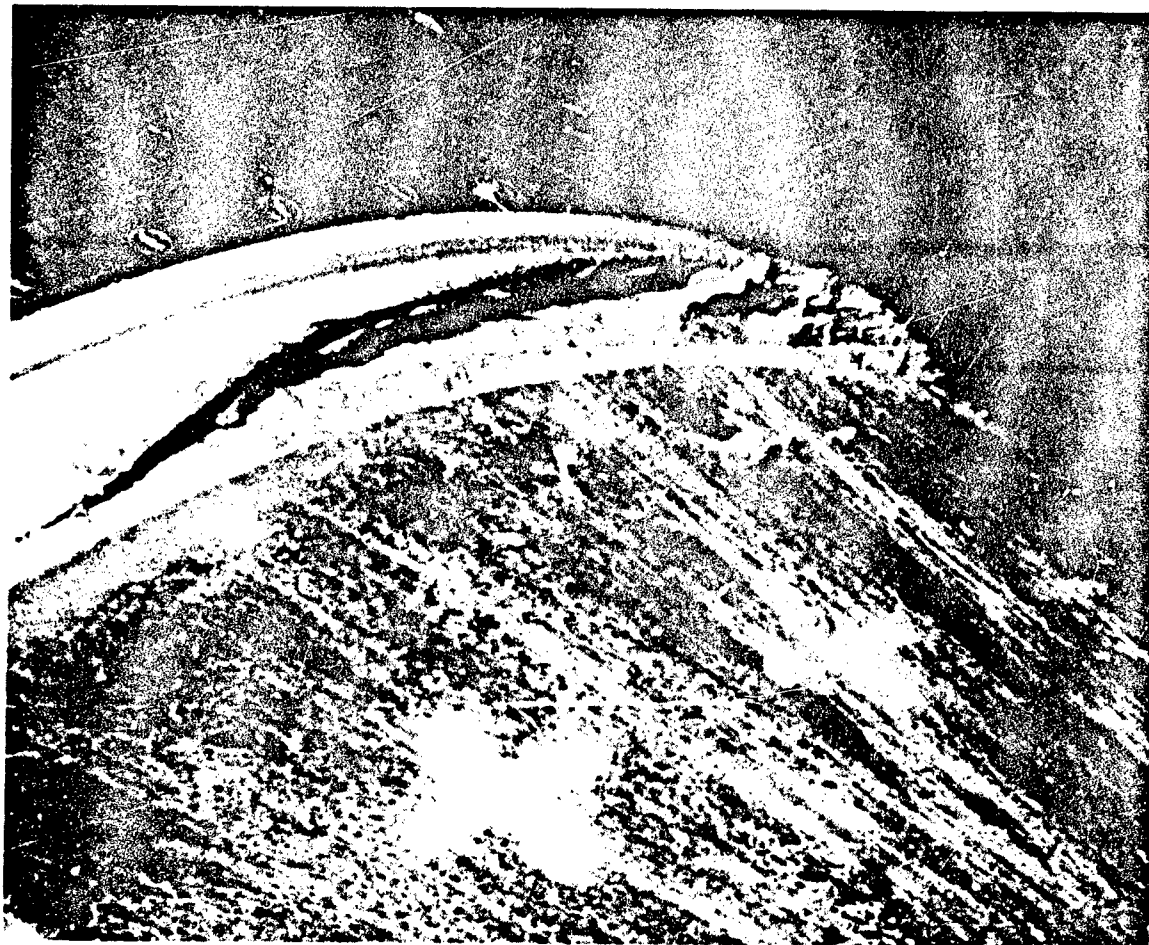
**FIGURE 14**

**TEST 2:**

**WINDSHIELD FAILURE**

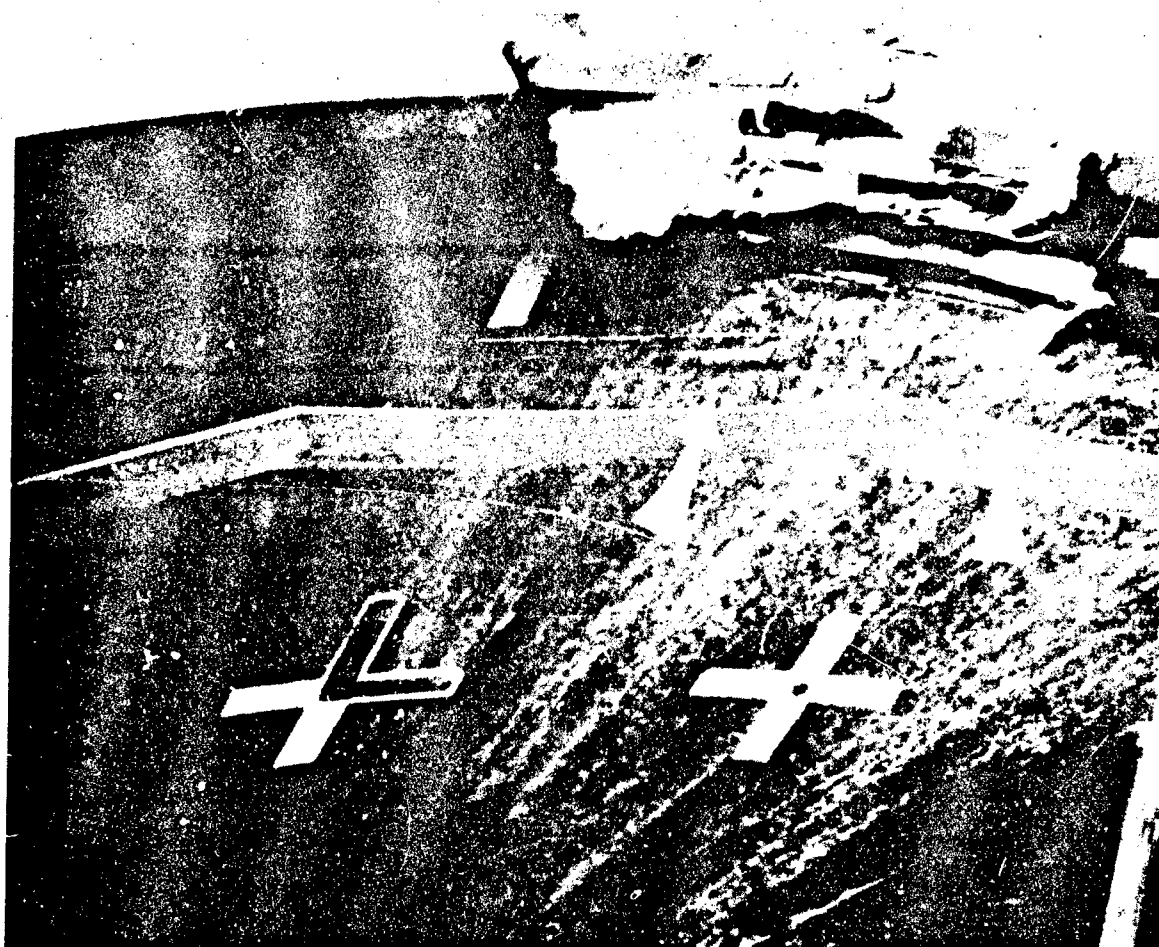


**FIGURE 15**  
**TEST 2:**  
**FORWARD COCKPIT DEBRIS**



**FIGURE 16**

**TEST 3:  
ARCH FLANGE DAMAGE**



**FIGURE 17**

**TEST 3:**  
**COMBINER GLASS SCORE MARK**

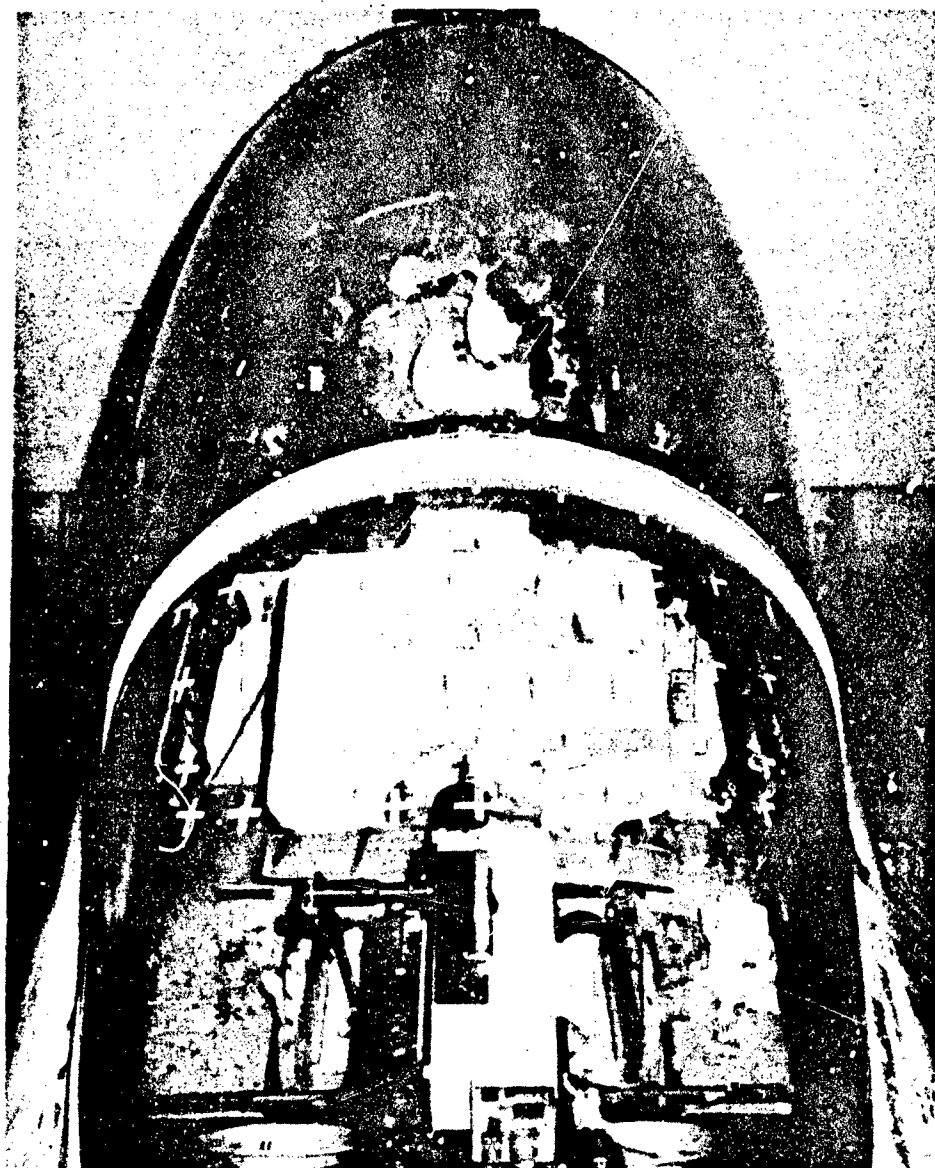
breaker bar at its minimum allowable clearance with the canopy. The proximity of the breaker bar may affect the response of the canopy during impact in a similar manner that the combiner glass affects the windshield. A new windshield, S/N A41-0313, and canopy assembly were installed for Test 4.

A 4-pound bird impacted the canopy at a speed of 496 knots resulting in damage to the simulated aircrew. A post-inspection revealed a 14 by 8 inch hole in the acrylic (Figure 18). The high speed film confirmed that the bird penetrated the monolithic acrylic and impacted the forward witness plate and ejection seat headrest (Figure 19). The ACESII ejection system did not interfere with the response of the canopy during bird impact. The forward seat shielded the aft crew member from bird debris and acrylic shards. However, the forward breaker bar detached, becoming a projectile that impacted the rear witness plate on the head (Figure 20). Test 4 was determined to be a "fail" due to bird penetration and heavy damage to the forward witness plate.

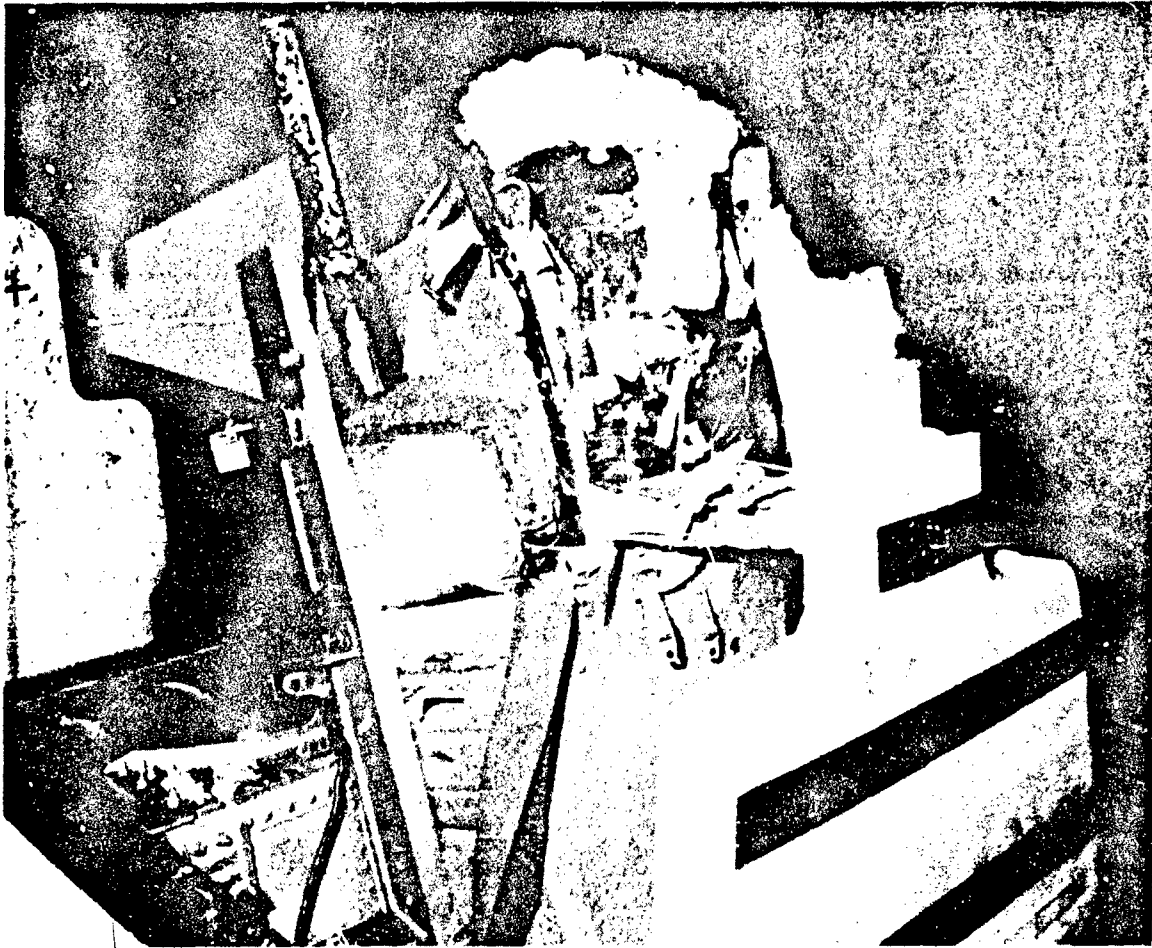
3.5 Test 5: Small Bird/High Speed The objective of Test 5 was to determine if a small bird could penetrate the windshield at a kinetic energy level within the birdstrike capability established in 4-pound testing. Based upon the results of Test 1, it was determined that the windshield by itself could withstand the kinetic energy associated with a 4-pound bird impact at 426 knots. To investigate the "feathered bullet phenomenon," the bird weight was reduced to two pounds and a speed of 530 knots was selected. This configuration was selected because it results in predicted stresses near the yield strength of stretched acrylic; however, the kinetic energy level is below that of Test 1. The reduced cross section of the small bird is illustrated in Figure 4 for the high quarter impact location. Windshield S/N A41-0313 was undamaged from Test 4 and utilized for Test 5. The canopy from Test 4 was removed and put in storage for possible future analysis. A second canopy assembly was prepared at Warner Robins and used for Test 5.

A 2-pound bird impacted the windshield high quarter location at 536 knots. The impact resulted in the windshield remaining structurally intact. A post-inspection revealed scuff marks on the windshield and minor arch damage (Figure 21). The result indicates that the selected conditions were below the impact tolerance of the system. Test 5 was determined to be a "pass."

# **TEST 4: BIRD PENETRATION**

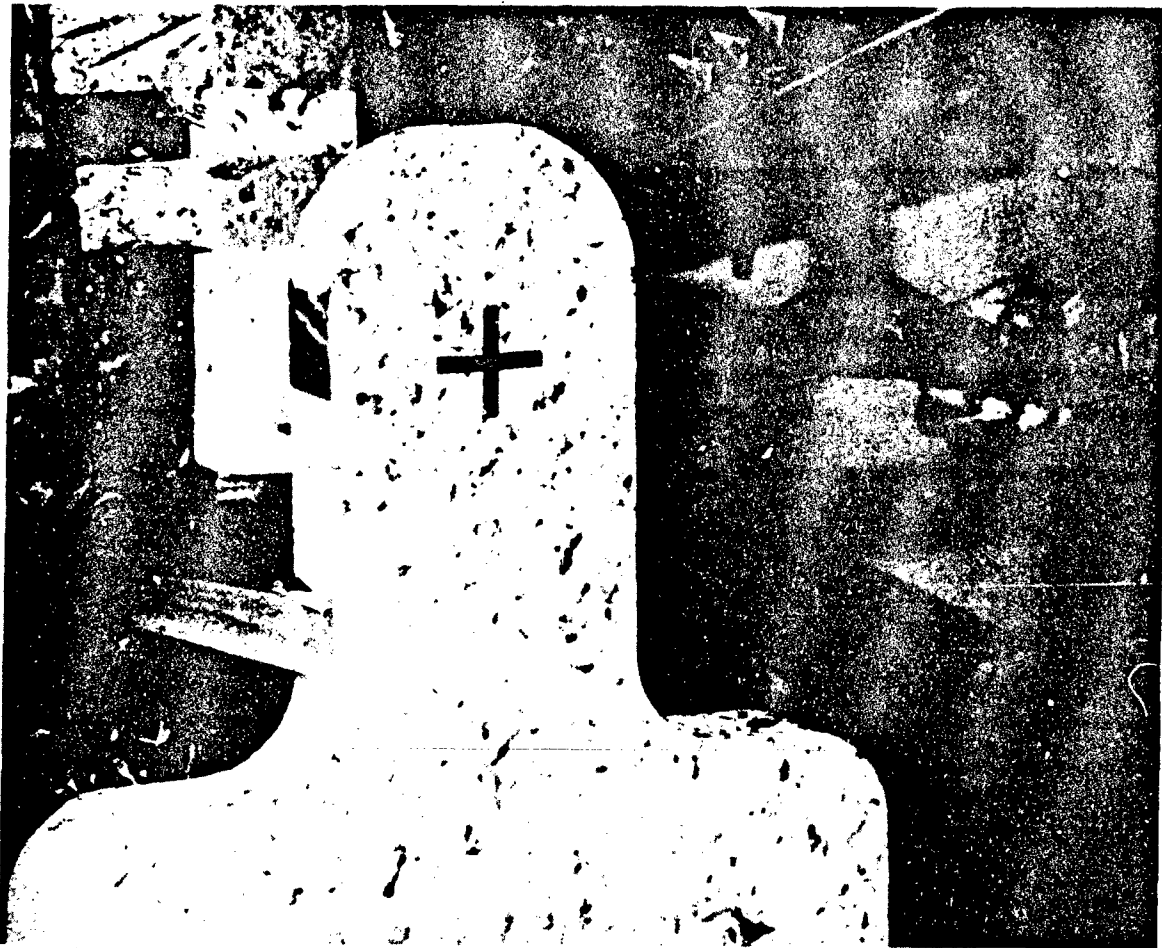


**FIGURE 18**

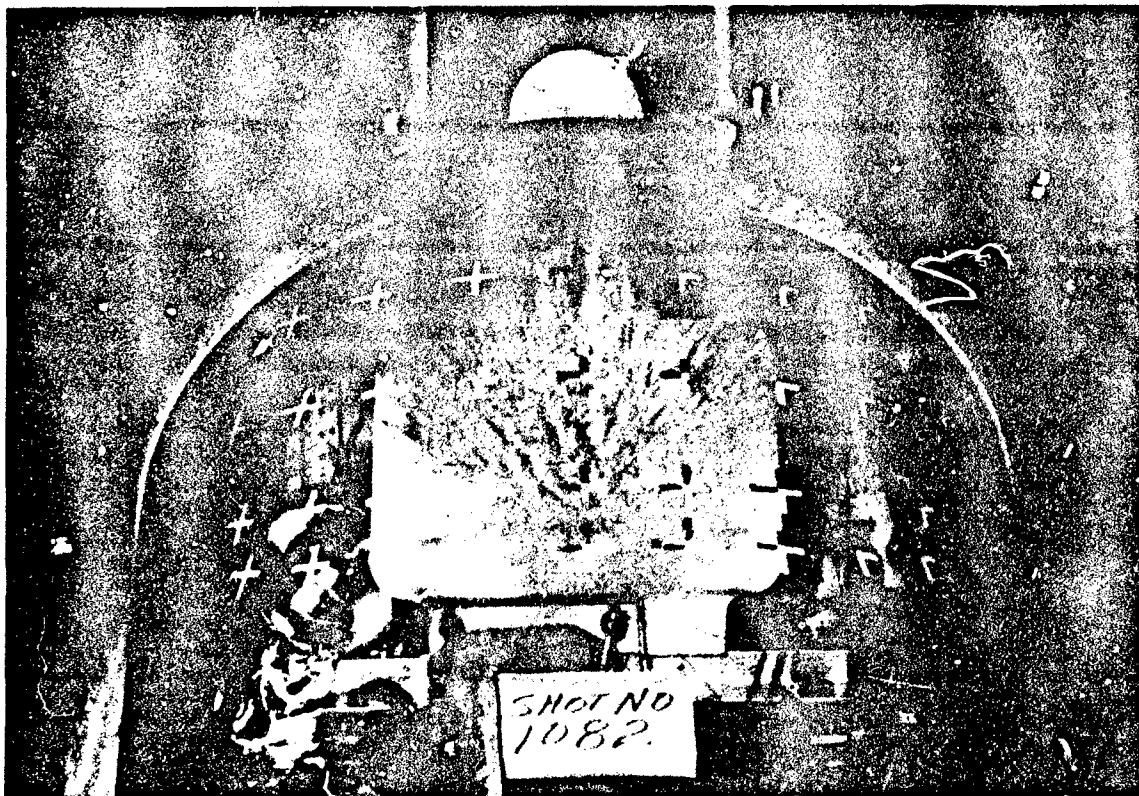


**FIGURE 19**  
**TEST 4:**  
**FORWARD WITNESS PLATE**

# **TEST 4: AFT WITNESS PLATE AND BREAKER BAR**



**FIGURE 20**



**FIGURE 21**

**TEST 5:  
SCUFF MARK, ARCH DAMAGE**

## 4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions This testing has provided the information required to address the safety concerns regarding the F-15E transparency system as well as the data necessary to initiate research of future transparency configurations. The results illustrate how the aircraft configuration affects the bird impact resistance of the F-15E transparency system. First, the presence of the wide field-of-view HUD combiner glass reduced the demonstrated 4-pound bird impact resistance of the F-15E production windshield to 395 knots at the high quarter. Second, the F-15E production canopy allowed a 4-pound bird to penetrate at a mission speed of 496 knots, resulting in heavy damage to the forward witness plate. Last, the ACESII ejection system did not interfere with the structural response of the production canopy during bird impact.

The deflection and strain data acquired throughout the testing will enable the validation of computer codes that model transparency systems and simulate the bird impact event. The small bird/high speed test has provided a starting point for research of the feathered bullet phenomenon effect on monolithic transparency systems. Tests 1 and 2 provided data needed to accurately model the transparency interaction with the wide field-of-view HUD. When comparing the data from this report with previous testing, the configuration must be accounted for. Specifically, the two degree angle of attack (AOA) attitude of the fuselage reduces the normal component of momentum imparted by the bird to the transparency compared to previous testing involving a fuselage at zero degrees AOA.

4.2 Recommendations The Strike Eagle spends over half its flight time in the bird environment (Figure 2), while traveling in excess of 400 knots for the better part of that time. However, the F-15E canopy is vulnerable to bird penetration at speeds above 170 knots and the windshield provides protection up to roughly 400 knots. The risk of a bird penetration resulting in fatality or loss of aircraft should be quantitatively defined. Birdstrike risk models have been formulated that predict the risk to a given aircraft configuration. The analysis should consider the test results mentioned in this report and historical birdstrike data on the F-15E aircraft as well as other aircraft which fly the low altitude high speed mission. Input data to the model includes fleet size, mission profile, flight hours, and bird population density.

Various transparency configurations and materials should be investigated that will provide the desired combination of bird impact resistance with other future design goals. Dynamic, non-linear, finite element codes are available that can simulate bird impact testing at a fraction of the time and cost of full-scale

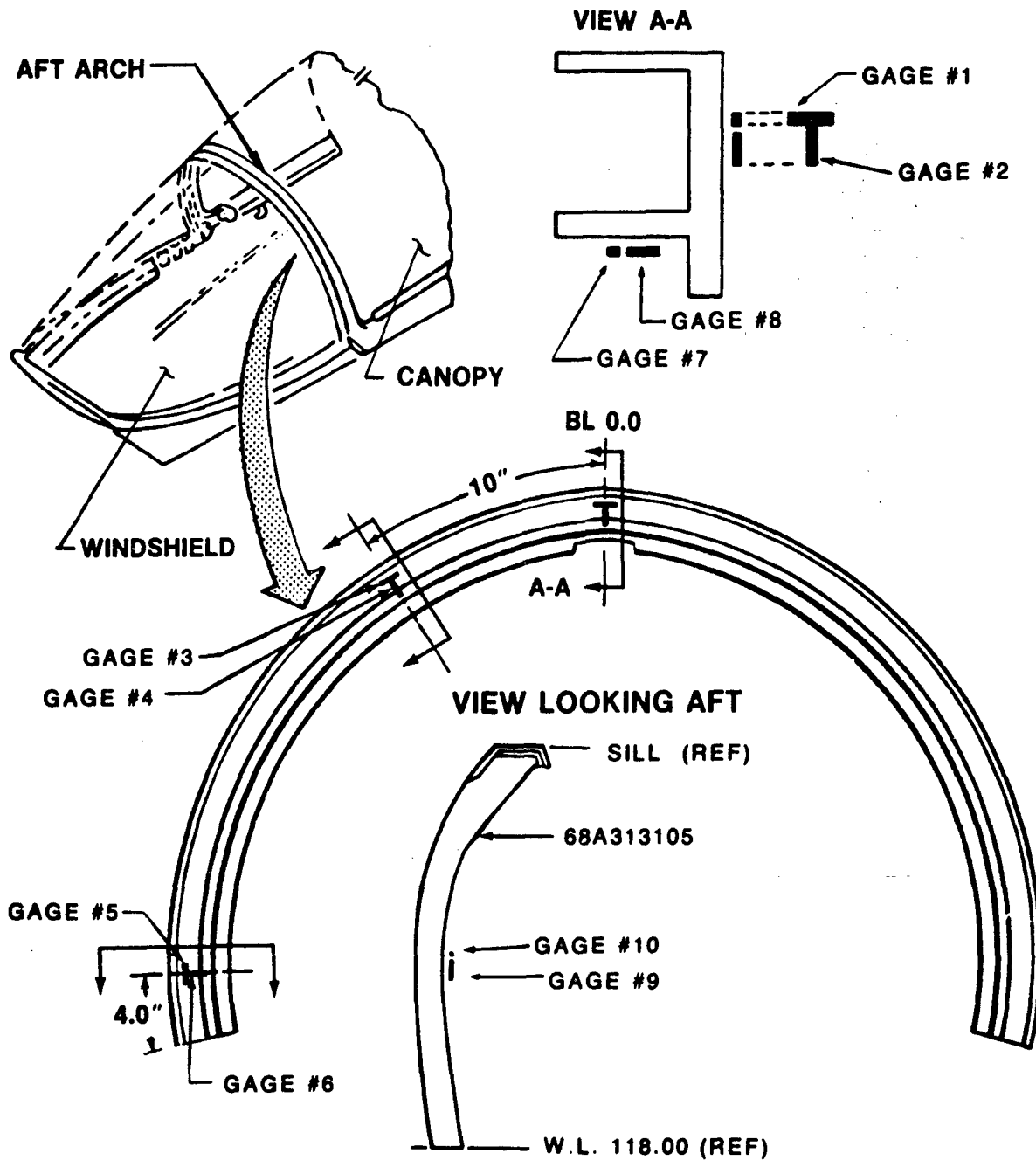
prototype fabrication and testing. The alternative design analysis should investigate several configurations, including laminate cross-sections, composite frames, and bolted edge fasteners. A sacrificial inboard ply in a laminate design may allow the windshield to contact the HUD combiner glass by attenuating the cracking that can lead to catastrophic structural failure in monolithic systems. The analysis should consider various transparency materials available including polycarbonate, glass, urethane, polyurethane, and silicone.

## 5.0 REFERENCES

1. MDC Report No. A4888, "Final Report: Windshield/Canopy Bird Impact Resistance," CP080GF858 Rev A, 1977.
2. MDC Report No. A9931, "F-15 DRF Bird Impact Test, Evaluation of Acrylic Windshield Modifications," 1983.
3. MDC Report No. B0551, "Final Report: F-15E Windshield Qualification Bird Strike Tests (SGE 1)," TIS No. CP080GD451, 1987.
4. Pinnell, Robert, "The Triangulation Program Z-248 GW BASIC User's Guide," Contract No. F33615-87-M-3411 2406.

# APPENDIX A

## STRAIN GAGE LOCATIONS

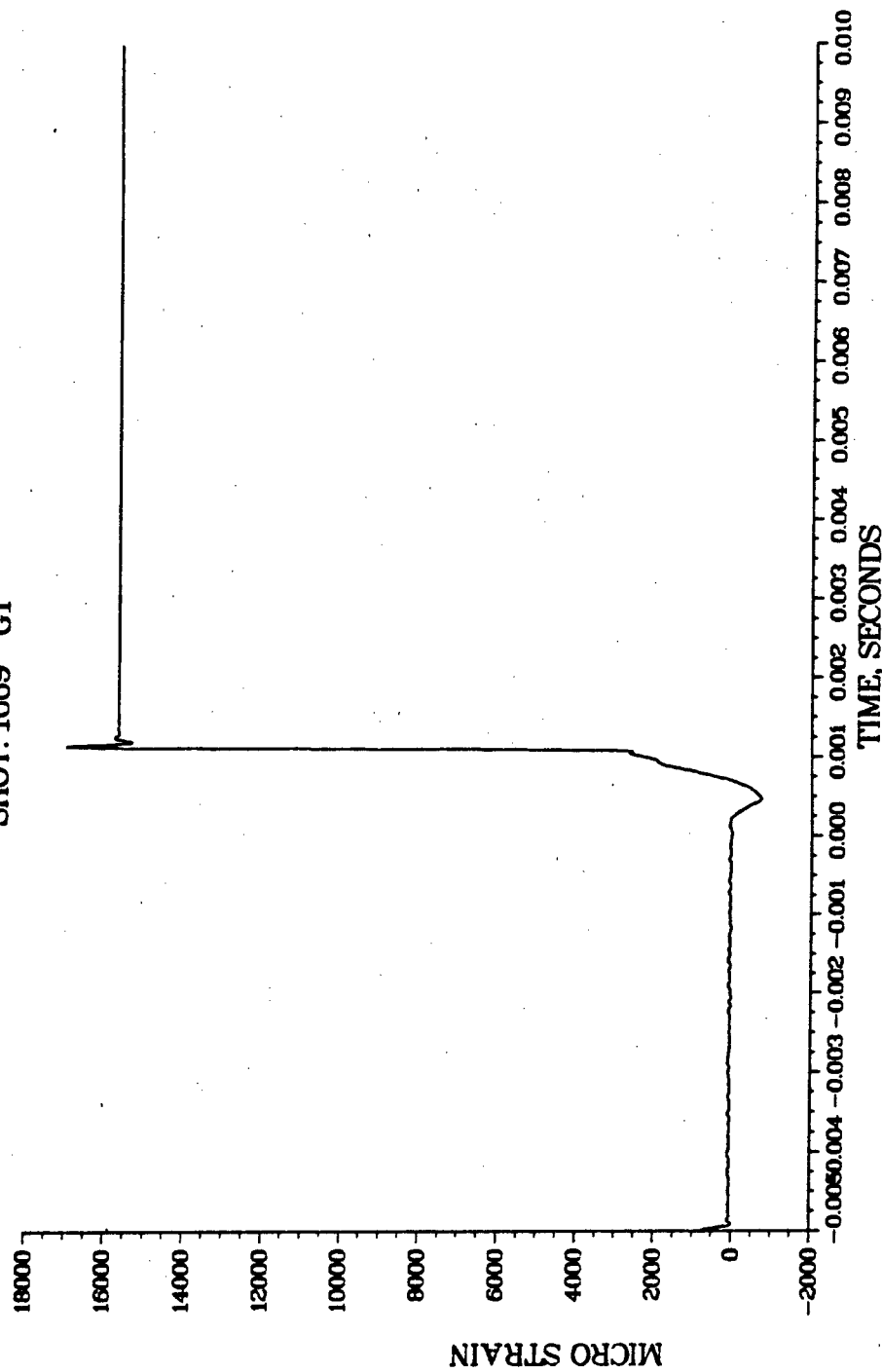


R/H FORMER FS 288.241

CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9438

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G1

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Low Frequency Cutoff = 0.0100MHz

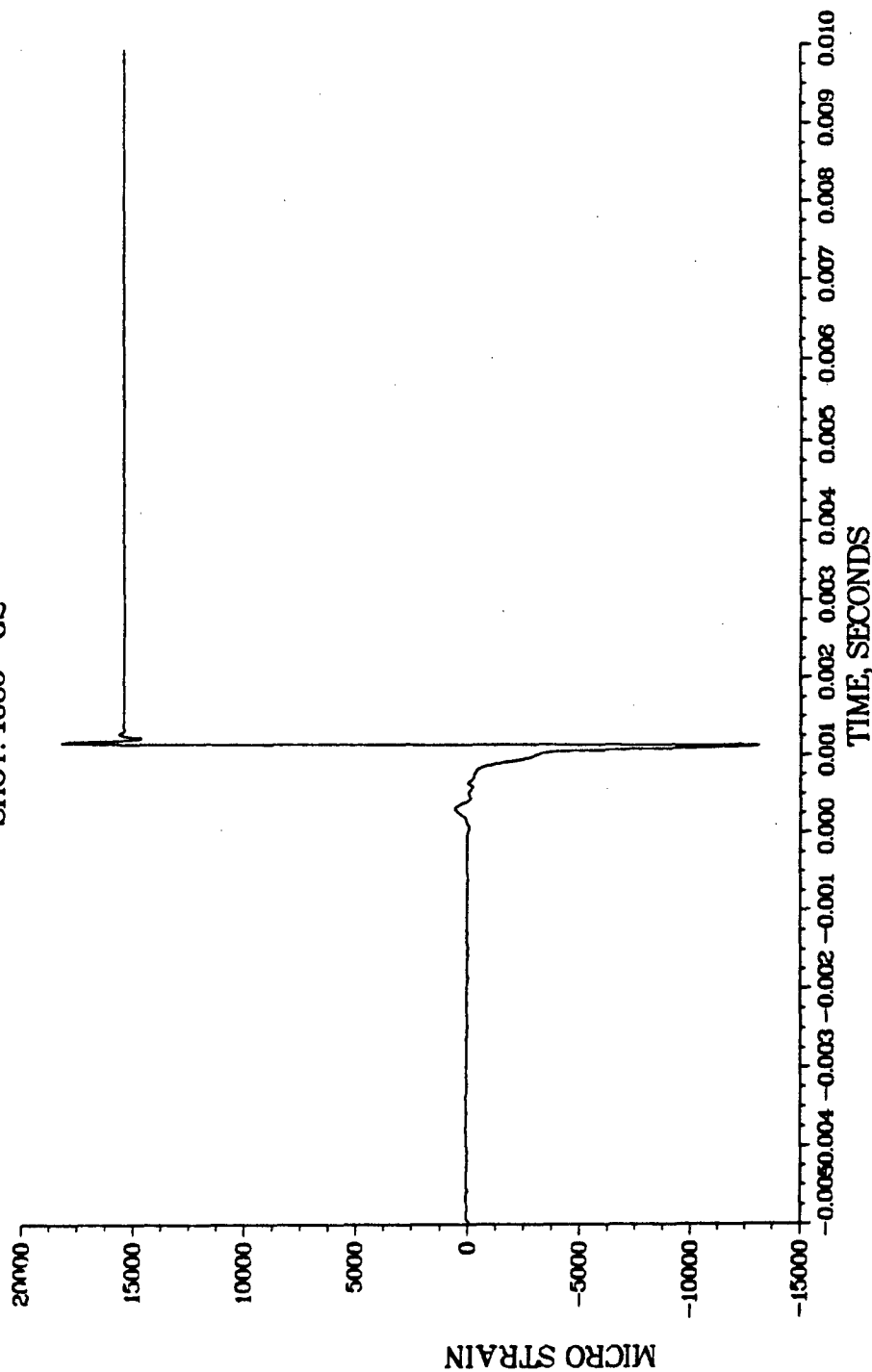


SCALE FACTOR = 3065.0

CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G2

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Low Frequency Cutoff = 0.0100MH

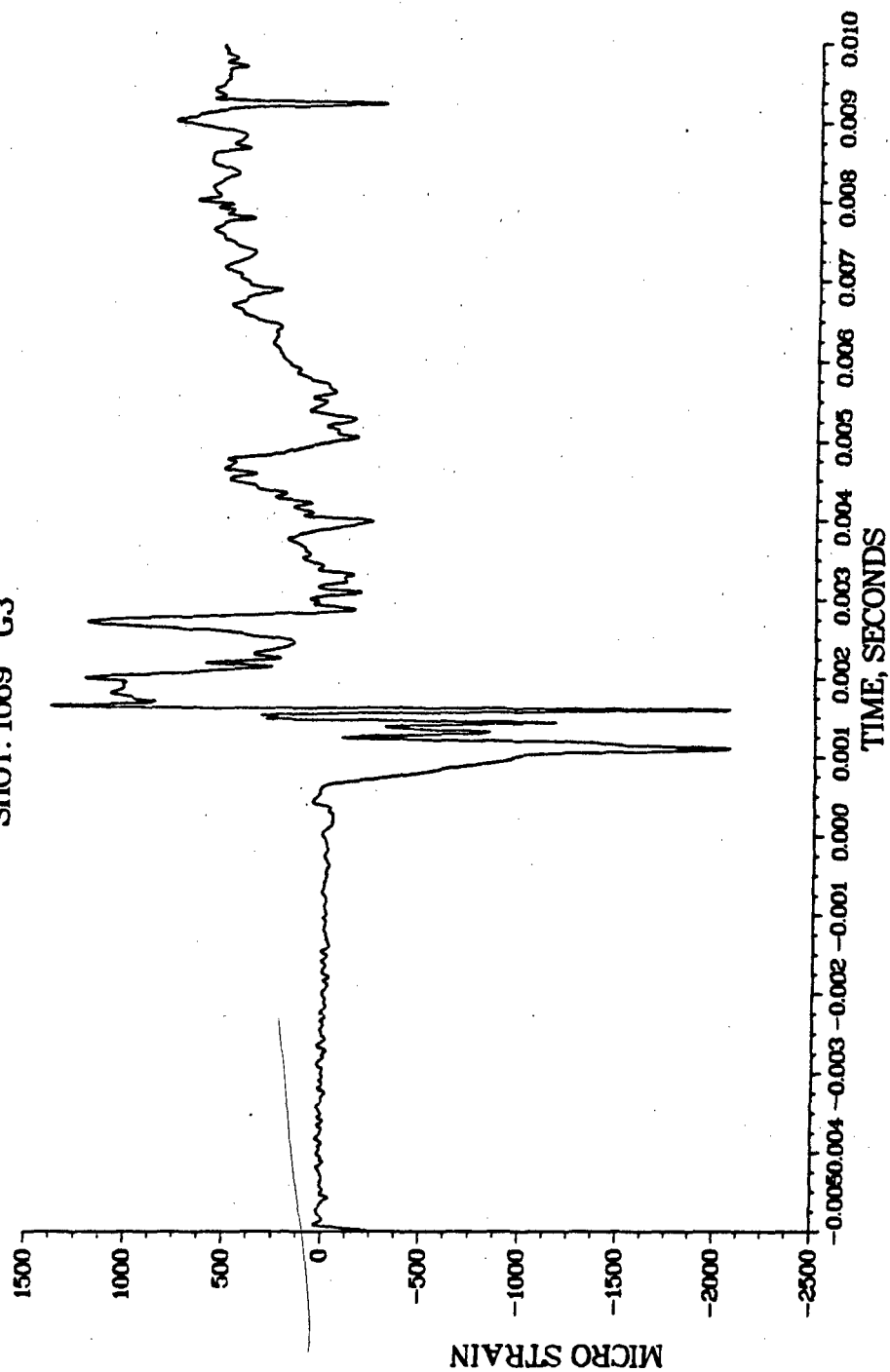


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-8888

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G3

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Low Frequency Cutoff = 0.0100MH

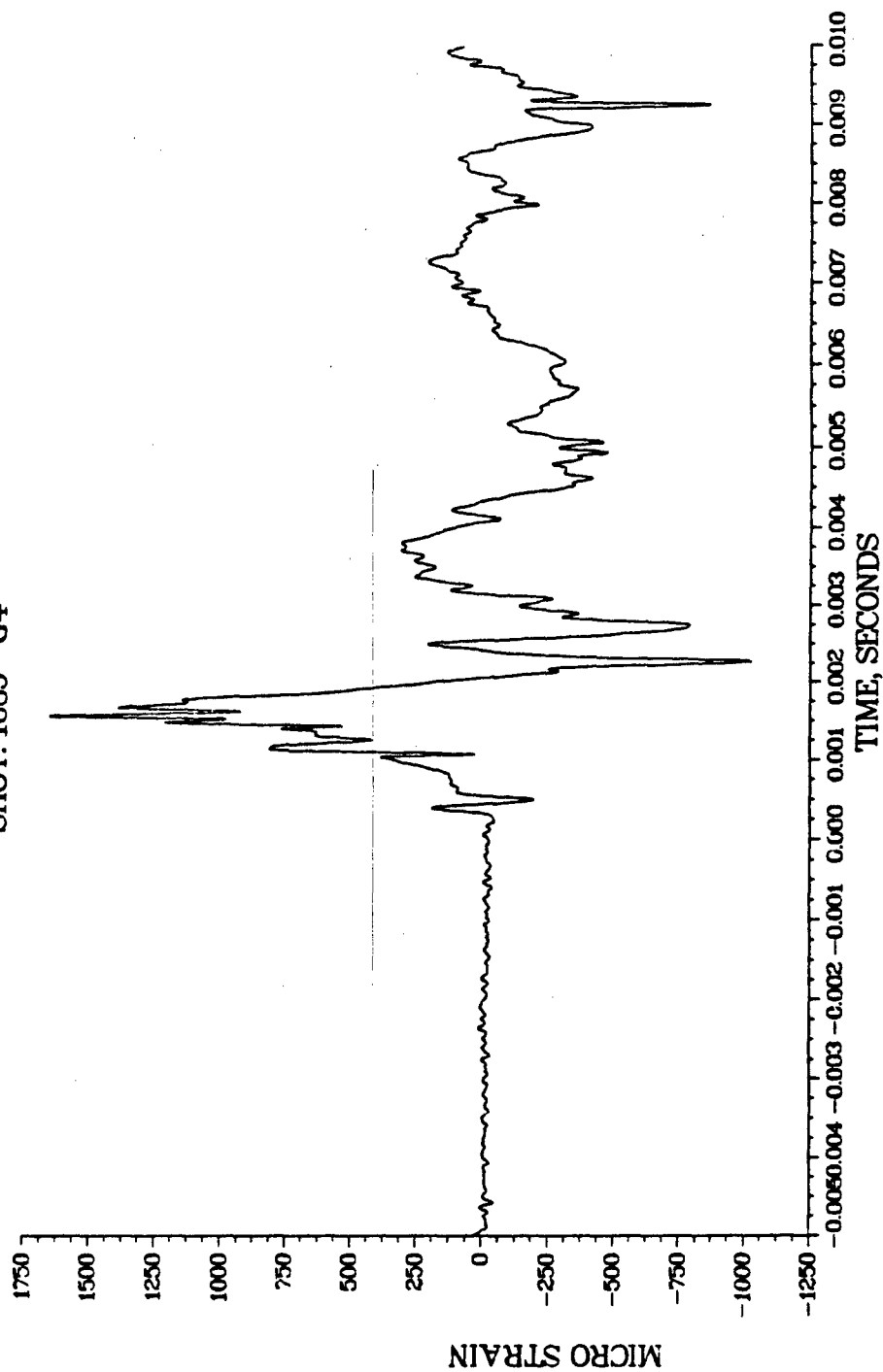


SCALE FACTOR = 2970.0

CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G4

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

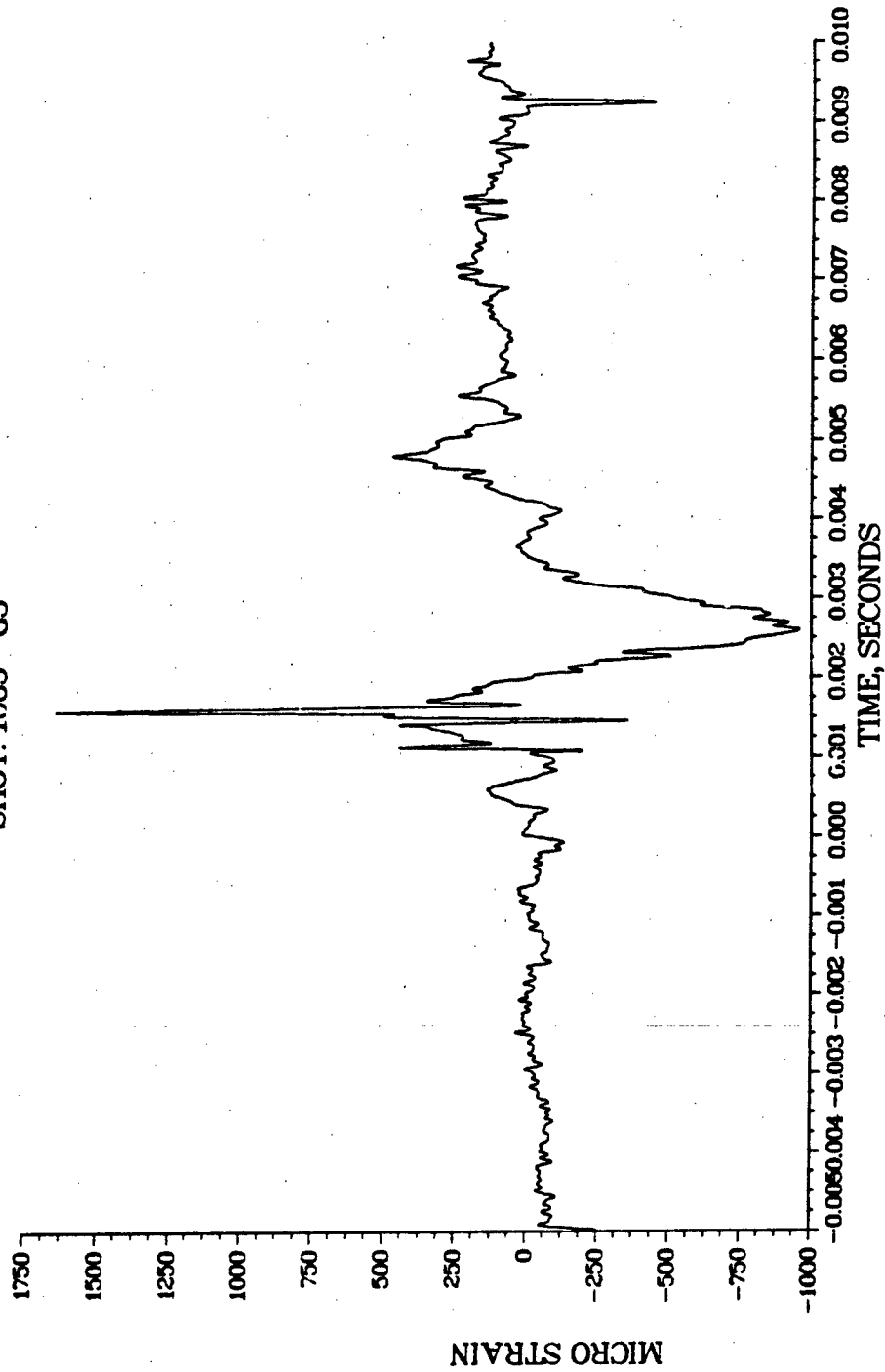


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR F. RCE BASE, TN 37389-8698

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 C5

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

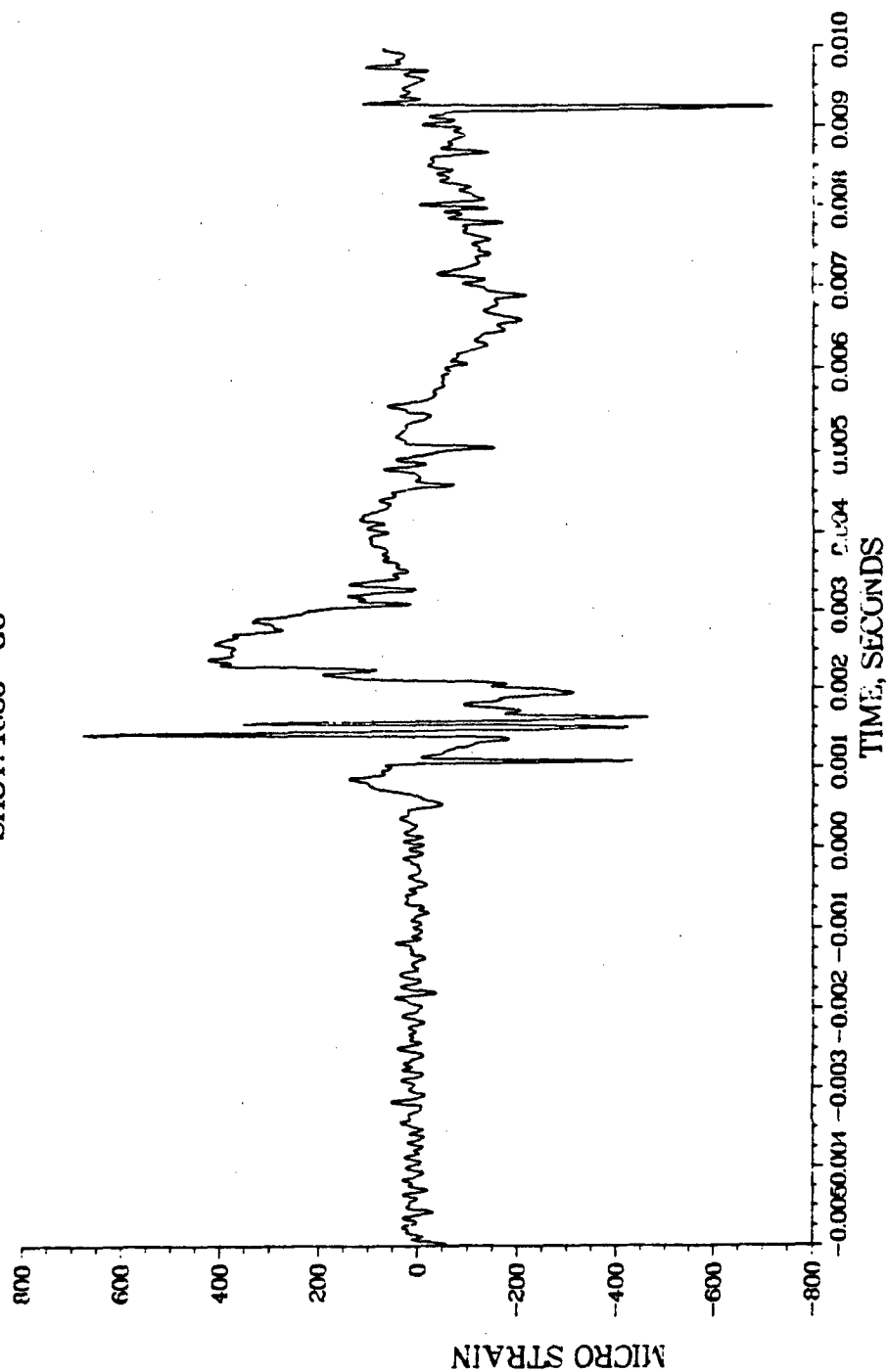


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CALSPAN CORPORATION / AFDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G6

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

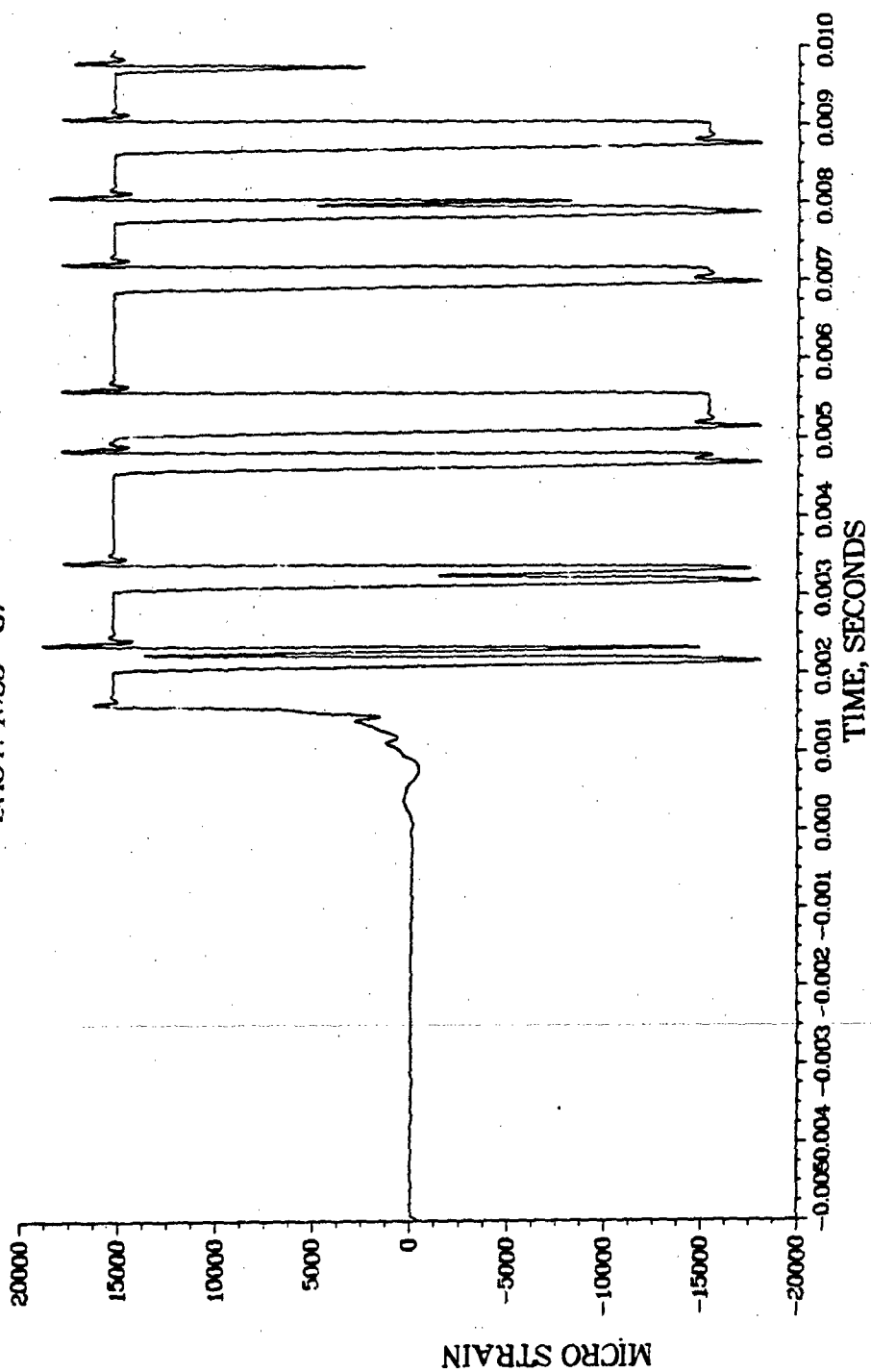


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CALSPAN CORPORATION / AEDC DIVISION  
ARMOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
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SHOT: 1069 G7

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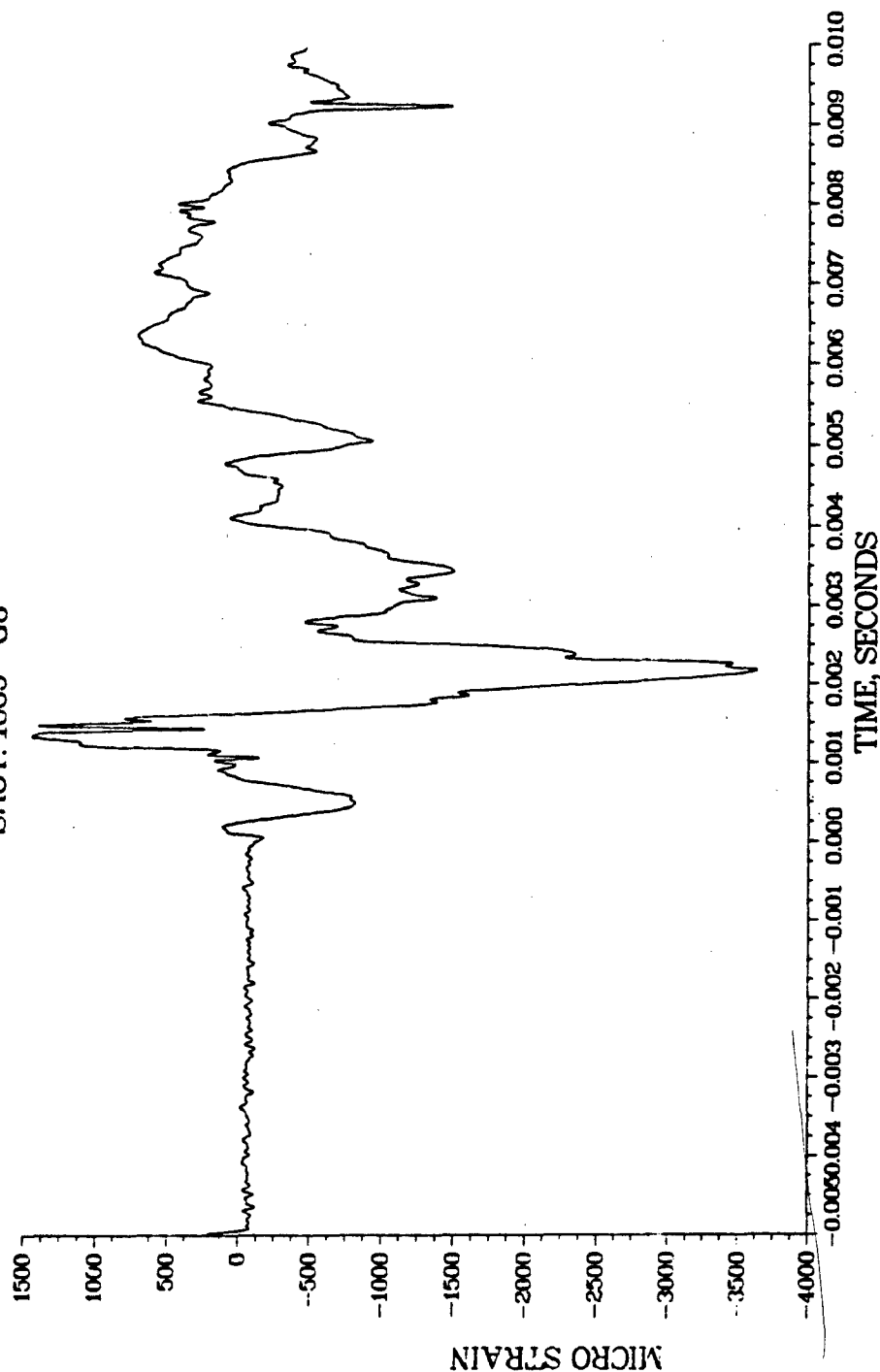


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G8

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Low Frequency Cutoff = 0.0100MH

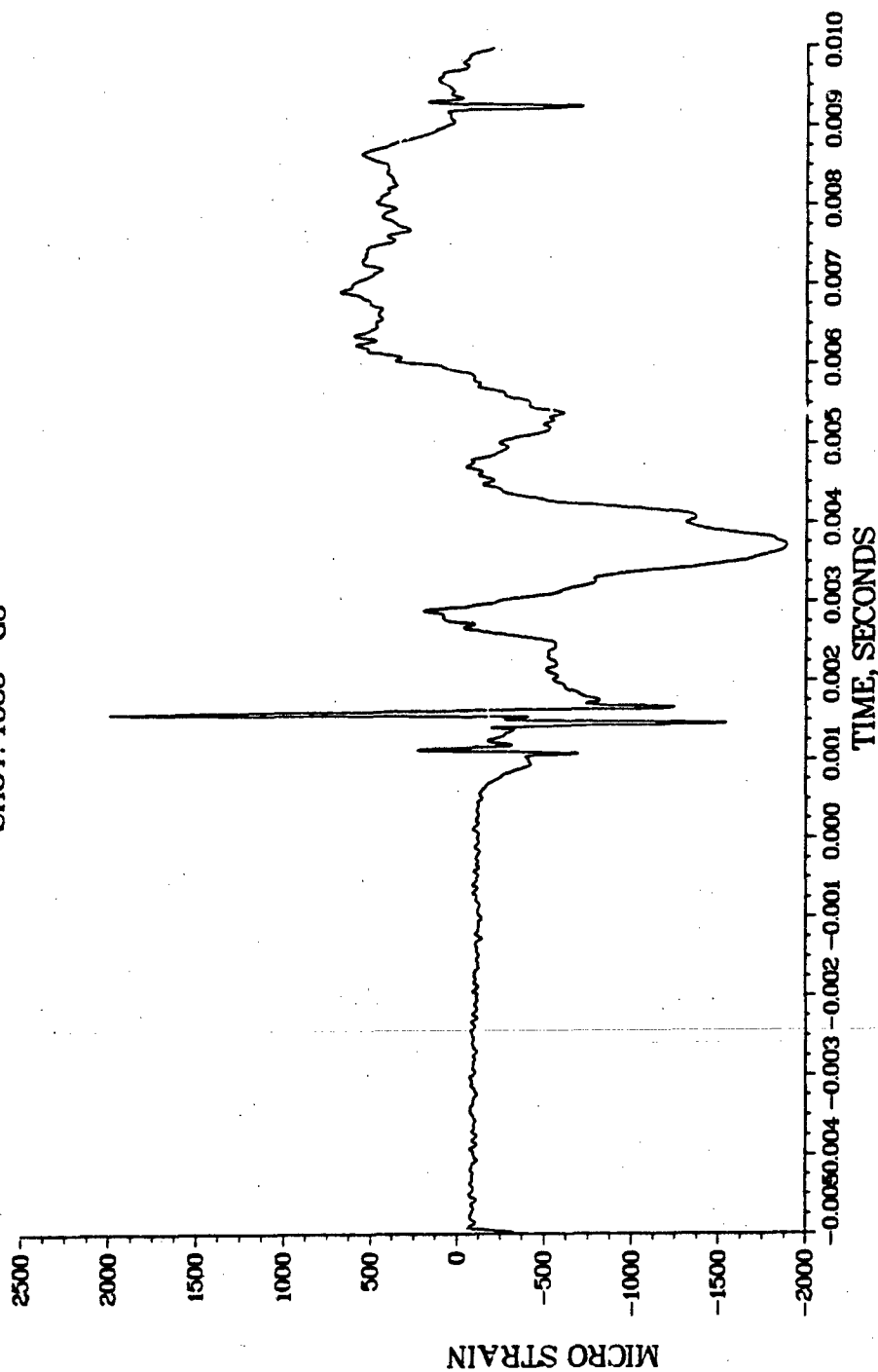


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CAUSTAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-5444

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G9

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

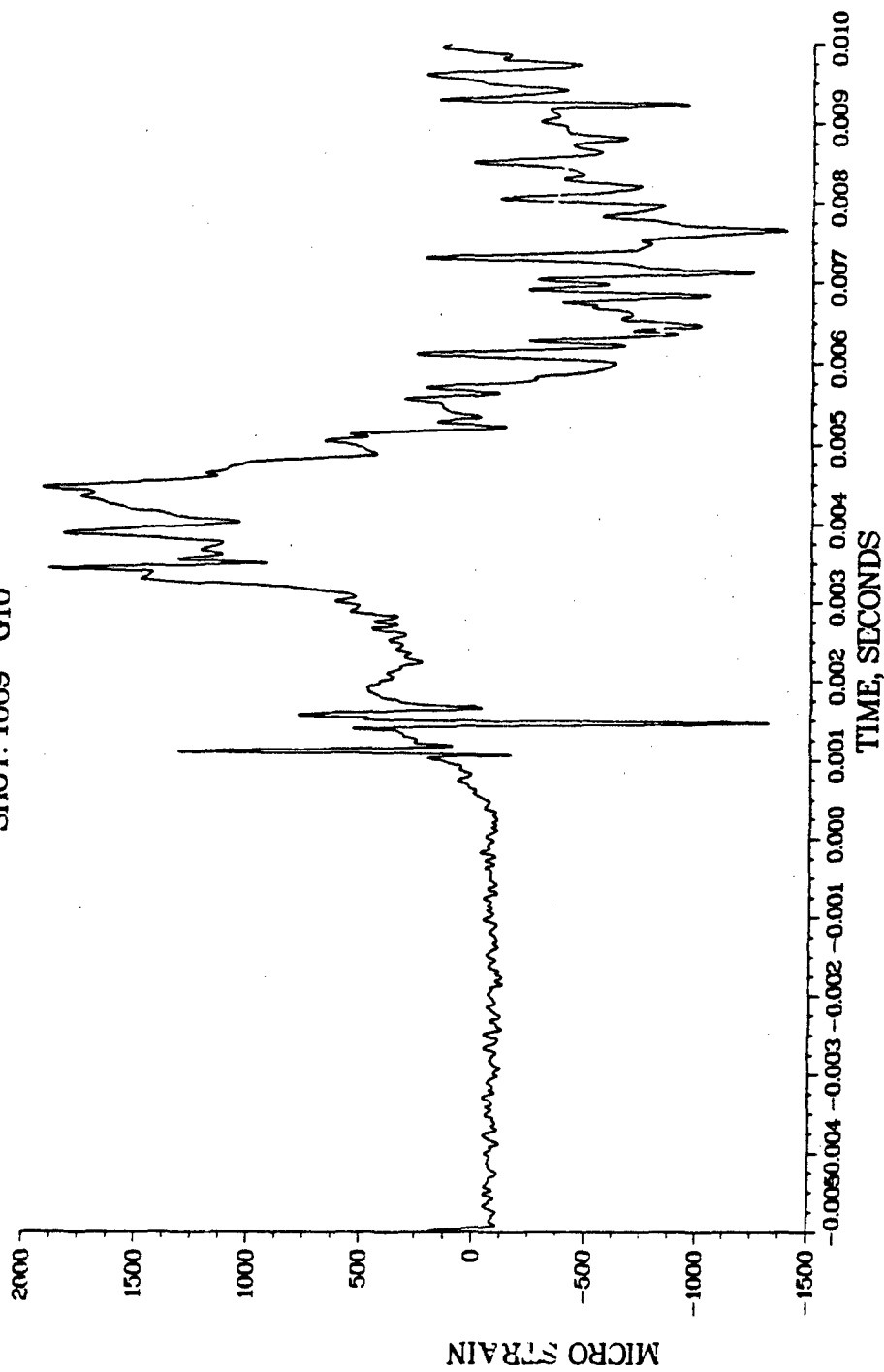


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-8998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1069 G10

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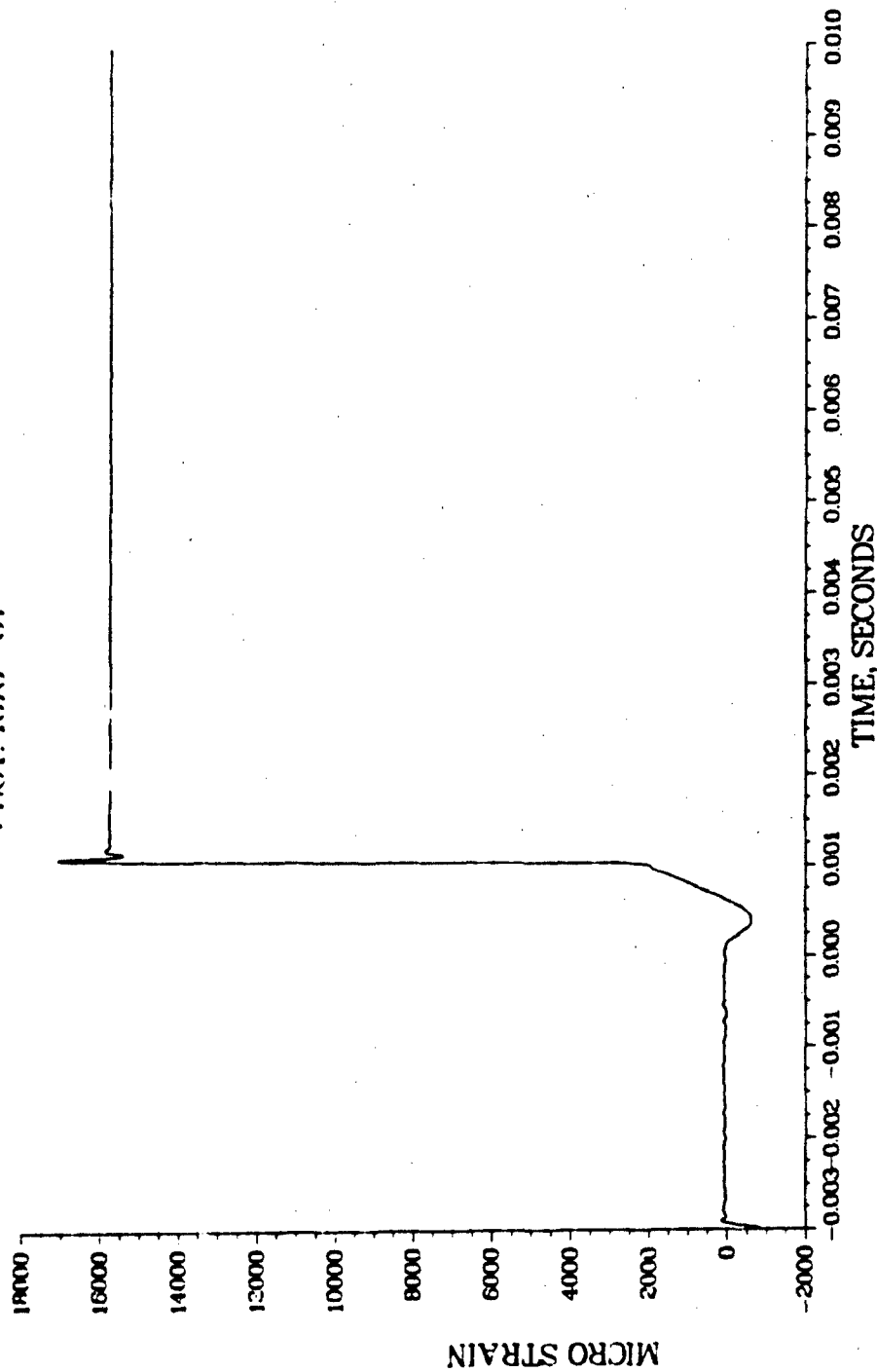


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CAESAR CORPORATION / AEDC DIVISION  
ARMED AIR FORCE BAL-7 TN 37189 9596

F15 BIRDSTRIKE  
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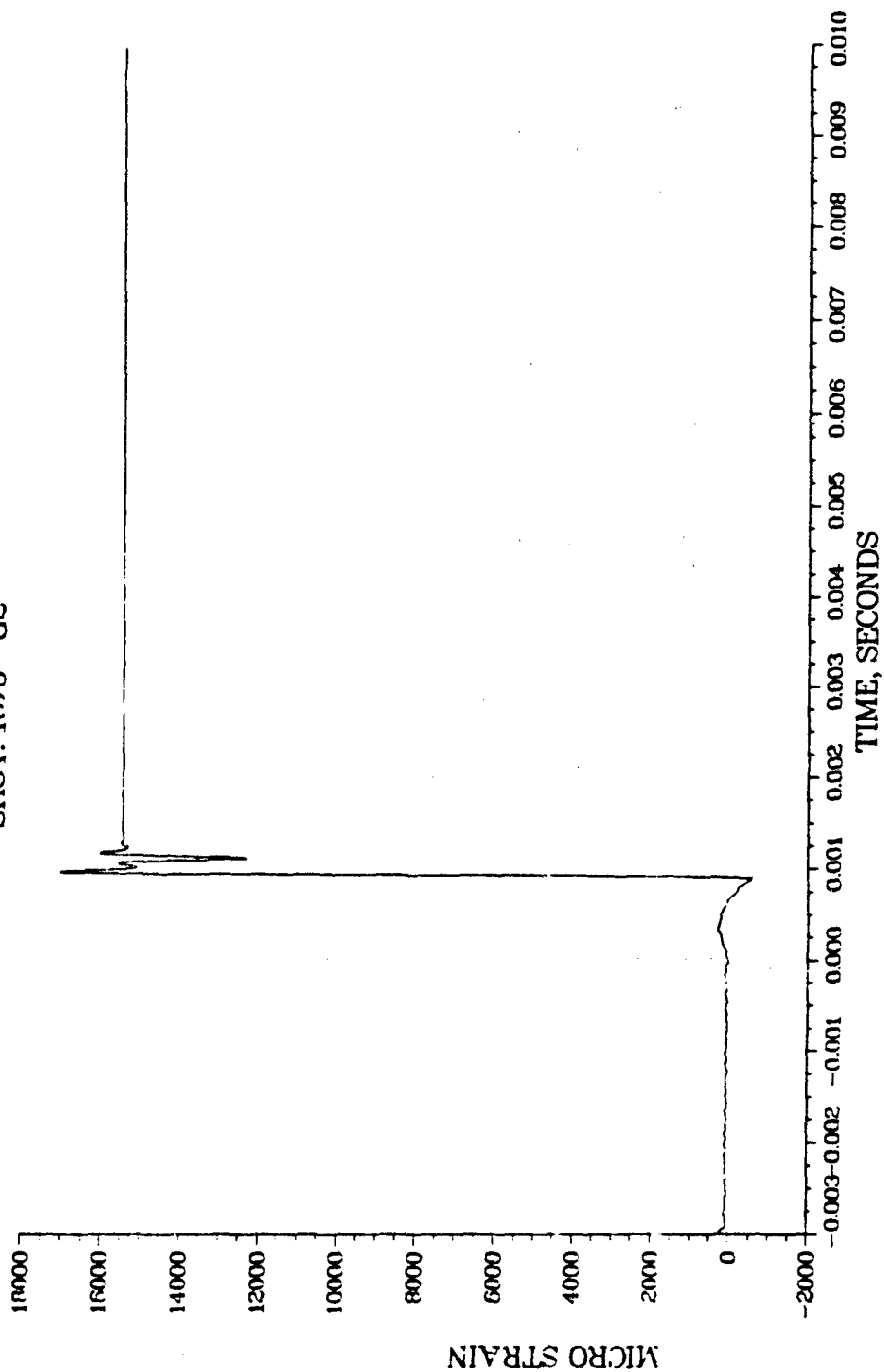
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CALSPAN CORPORATION / AETC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 HIRDSRIKE  
CQ21VJ  
SHOT: 1070 G2

Lowpass Filter  
Low Frequency Cutoff = 0.0100MHz

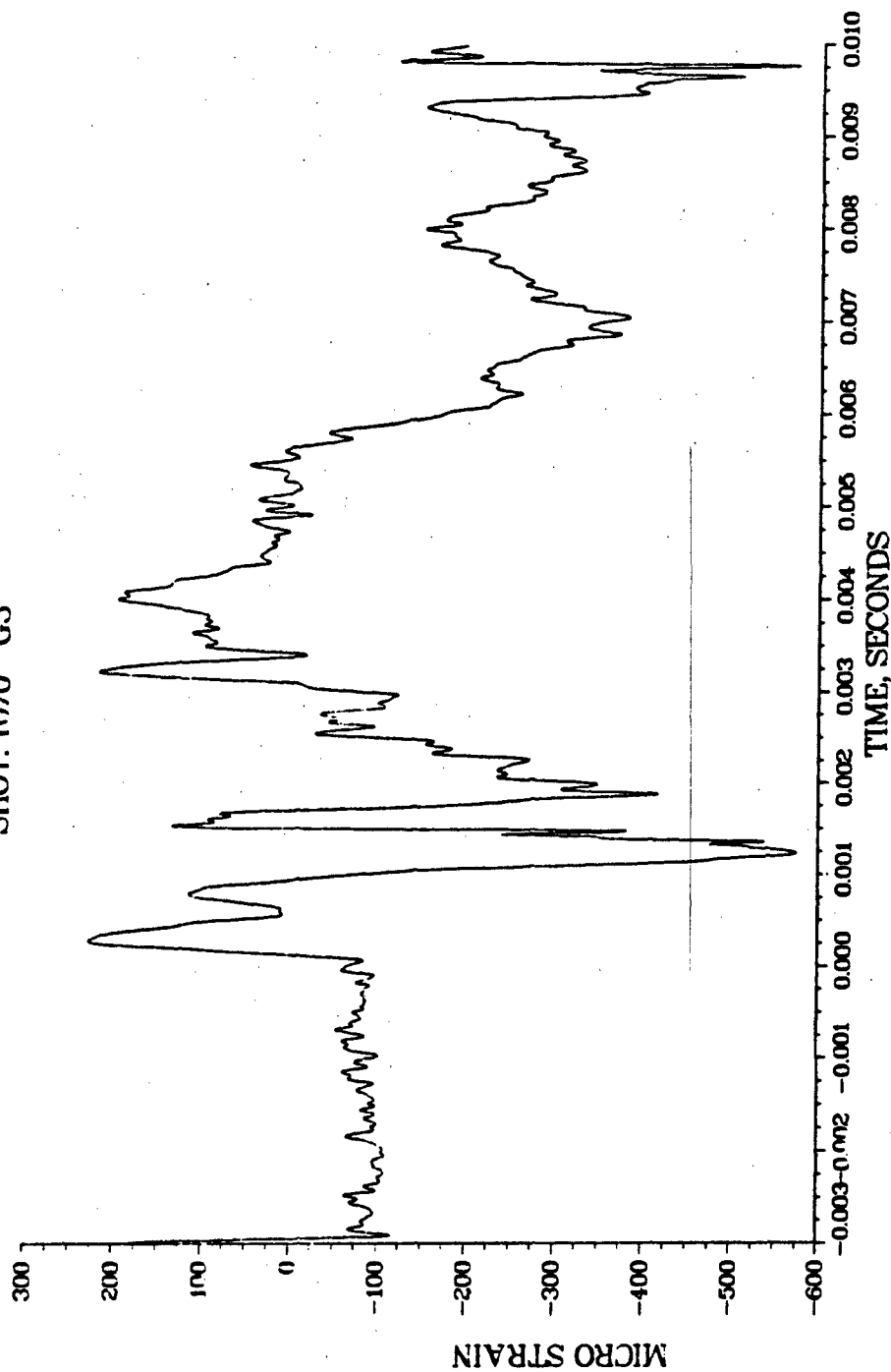


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37189-9998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1070 G3

Lowpass Filter  
Low Frequency Cutoff = 0.0100MHz

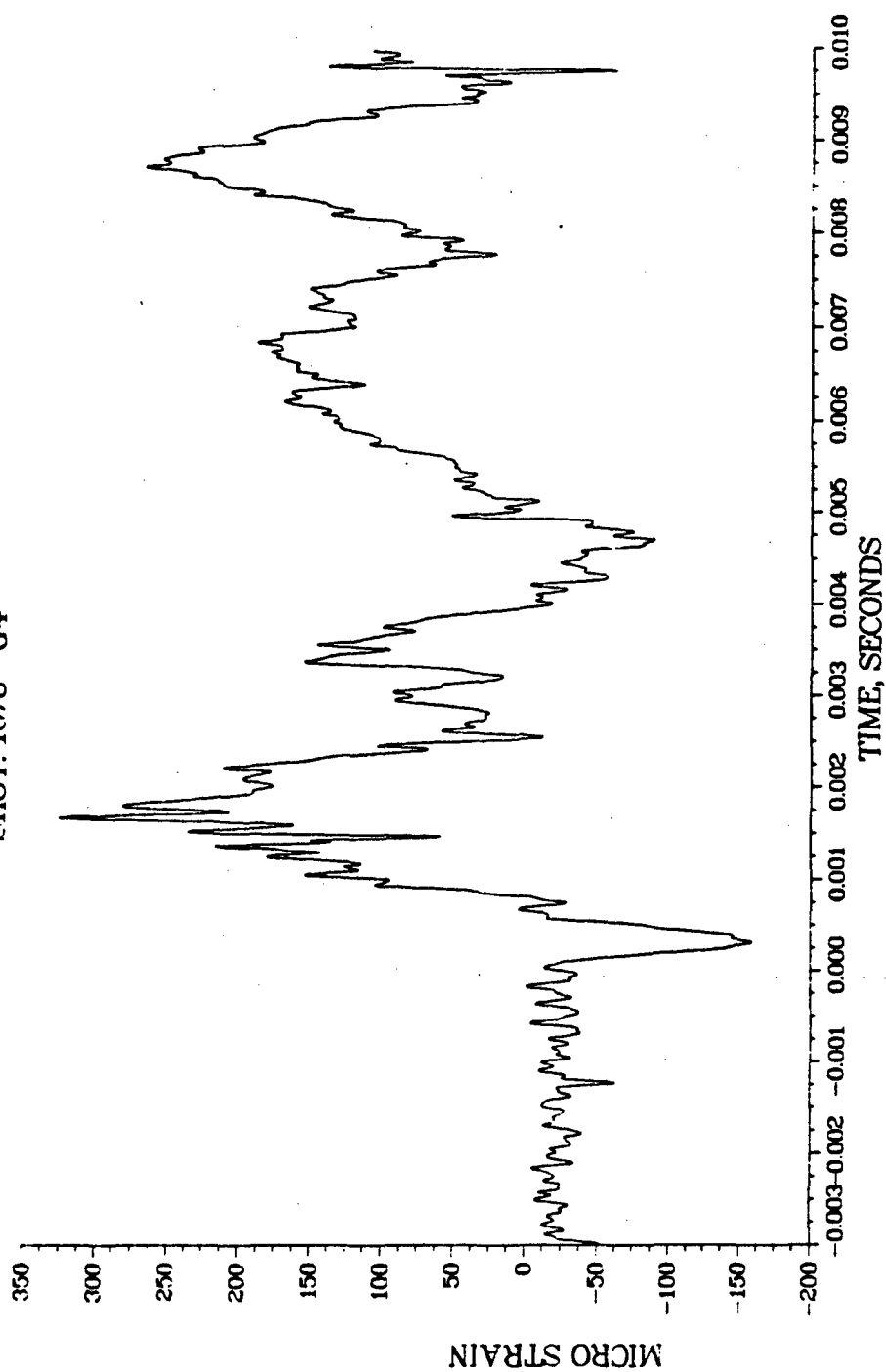


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CALSPAN CORPORATION / AETC DIVISION  
ARNOLD AFB, FORTE BASE, TN 37389-9996

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1070 G4

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

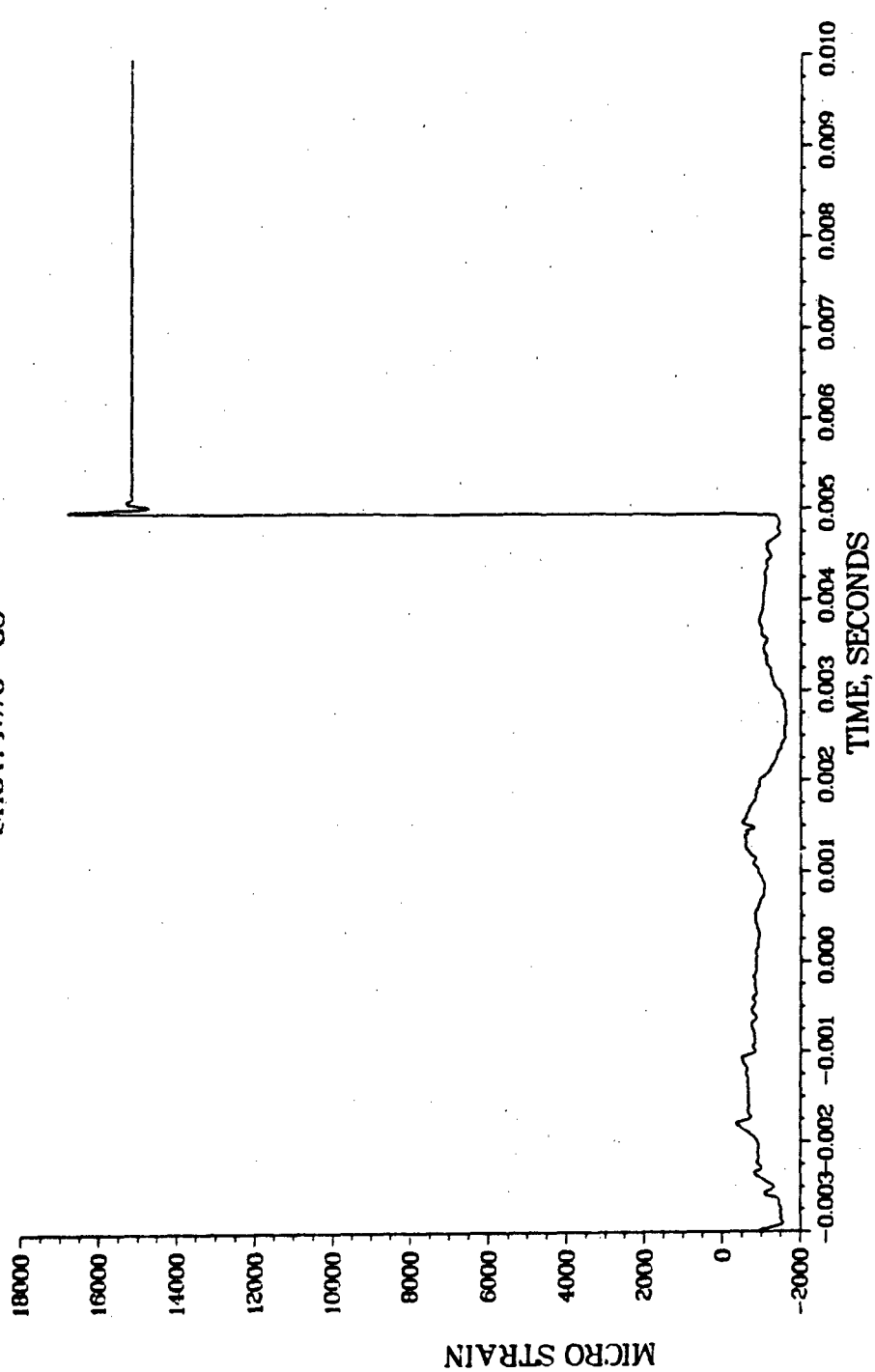


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CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 HIRDSTRIKE  
CQ21VJ  
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Lowpass Filter  
Low Frequency Cutoff = 0.0100MHz

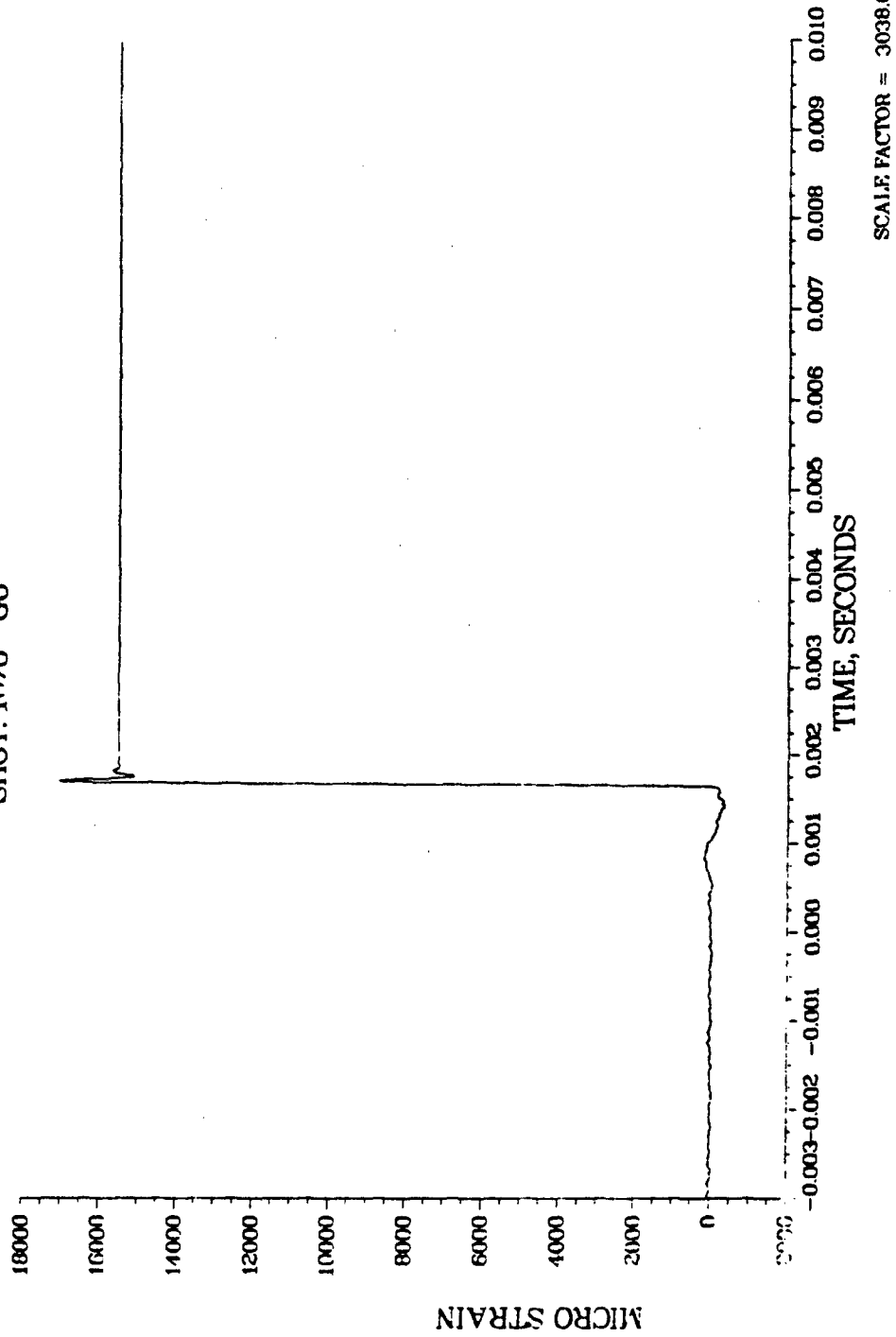


SCALE FACTOR = 2974.0

CALSPAN CORPORATION / ARDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9998

F15 BIRDSTRIKE  
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SHOT: 1070 G6

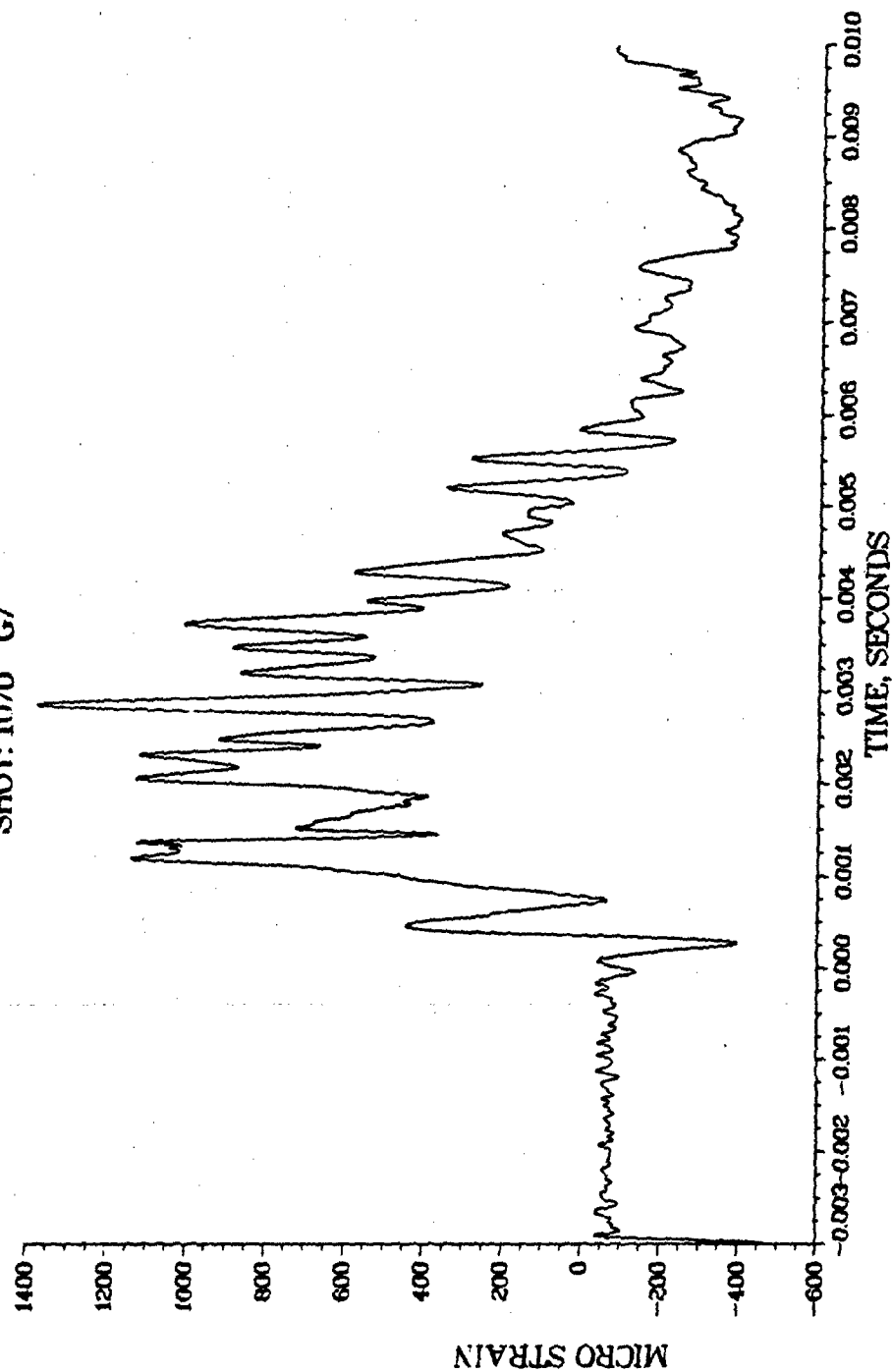
Lowpass Filter  
Low Frequency Cutoff = 0.0100MH



CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-8998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1070 G7

Low Pass Filter  
Low F: Frequency Cutoff = 0.0100MH

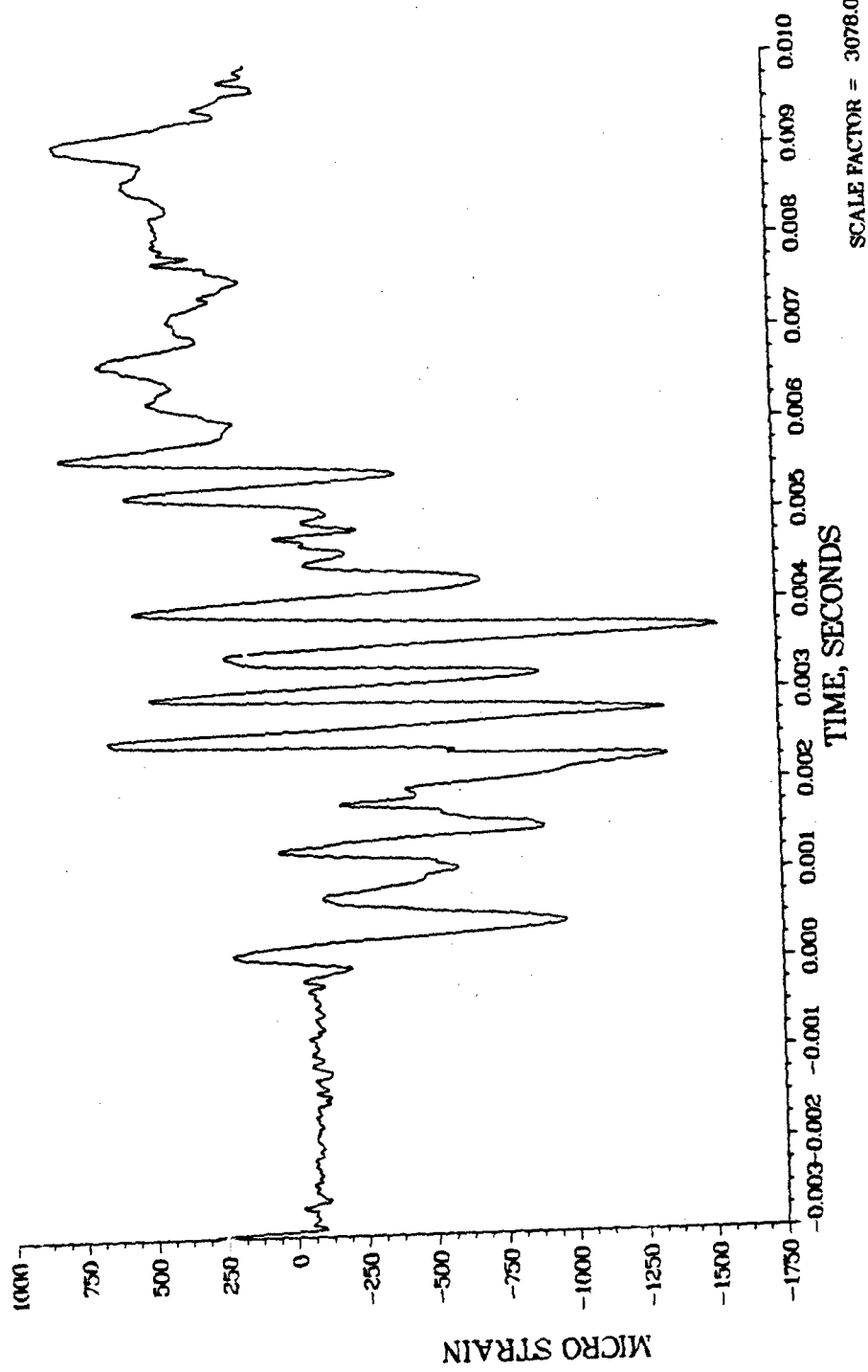


SCALE FACTOR - 3027.0

CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37369-9998

F15 BIRDSTRIKE  
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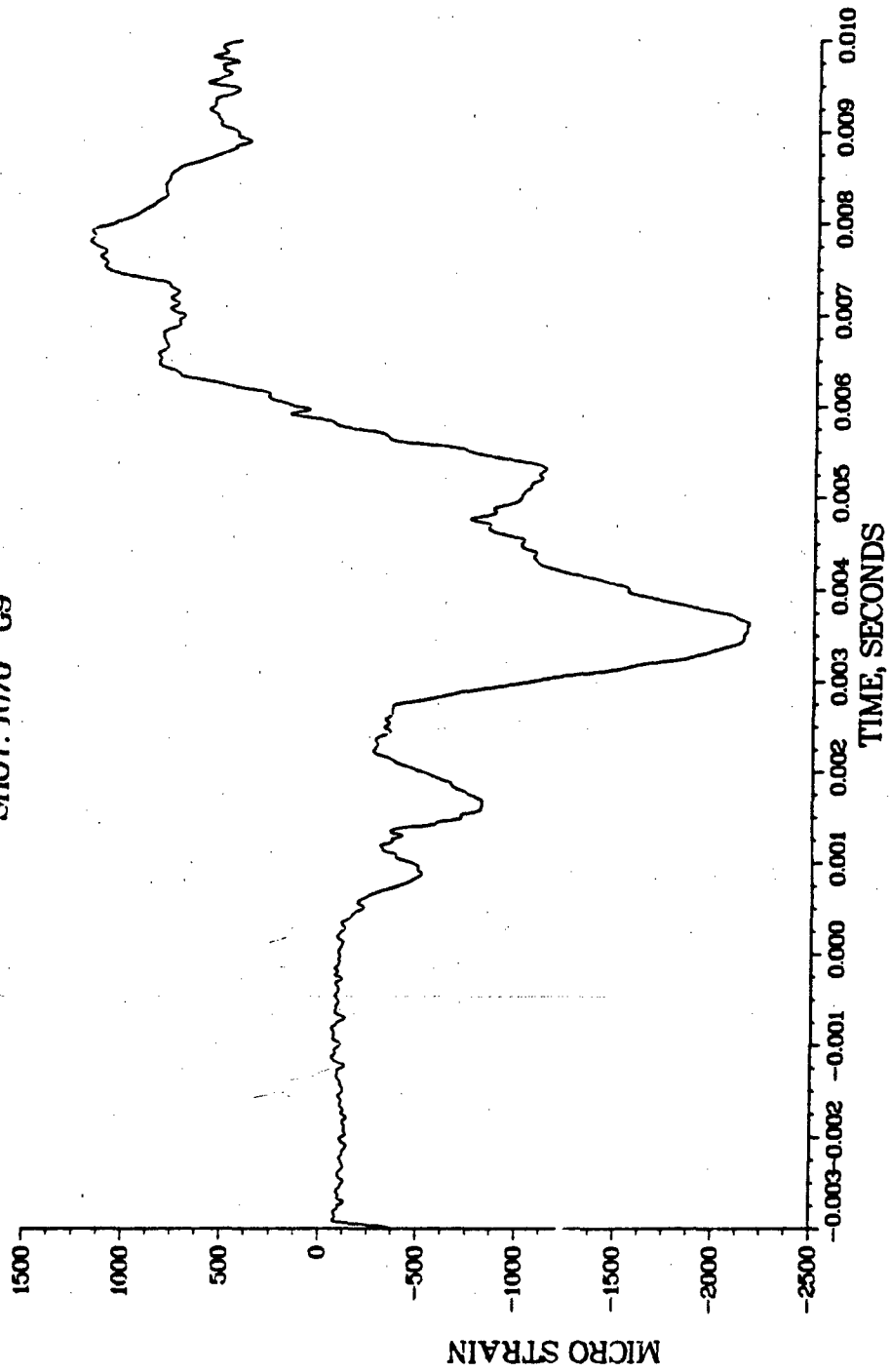
Low pass Filter  
Low Frequency Cutoff = 0.0100MH



CALSPAN CORPORATION / ARDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-8998

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1070 G9

Lowpass Filter  
Low Frequency Cutoff = 0.0100MH

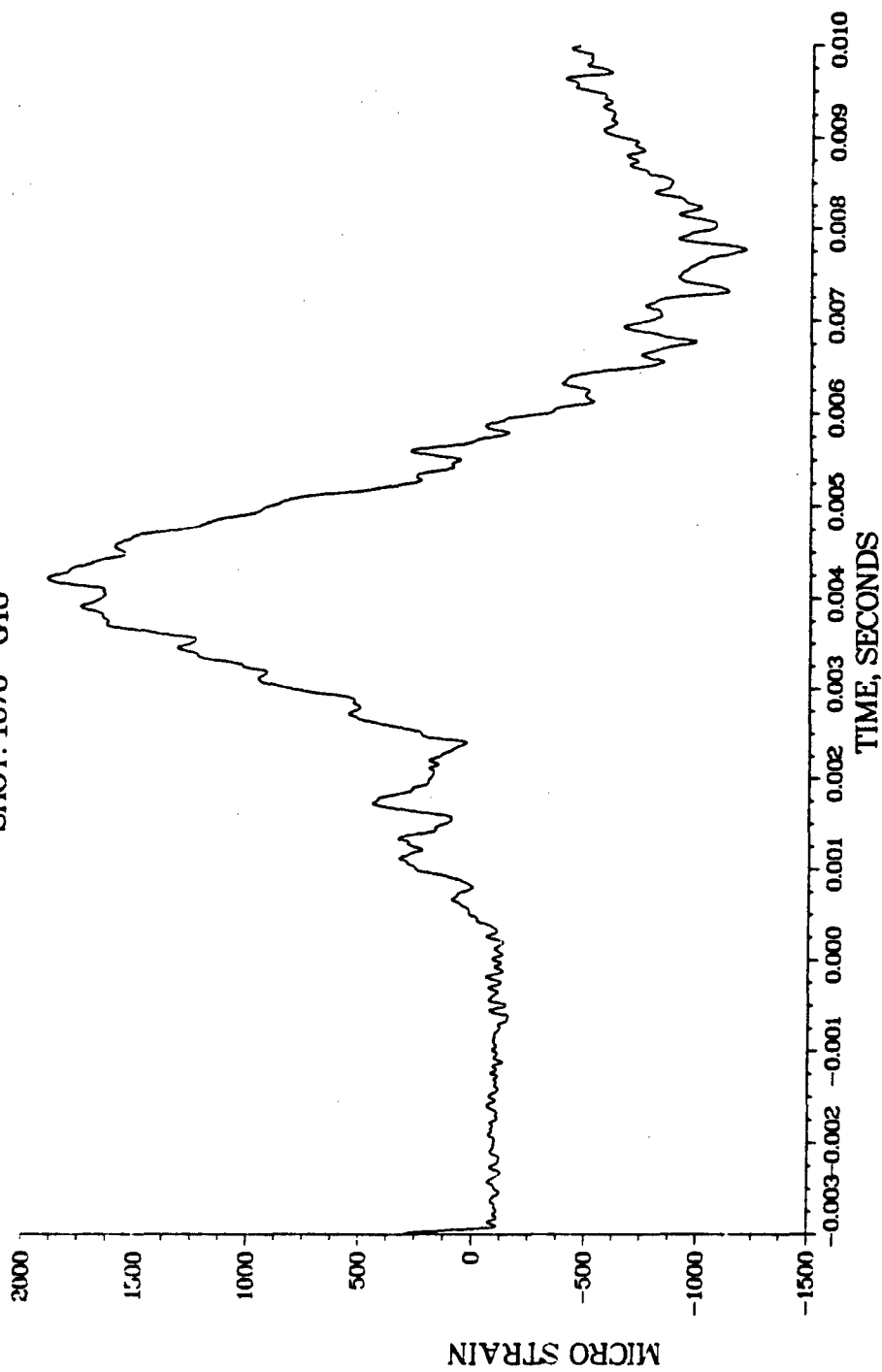


SCALE FACTOR = 3023.0

CALSPAN CORPORATION / AEDC DIVISION  
ARNOLD AIR FORCE BASE, TN 37389-9938

F15 BIRDSTRIKE  
CQ21VJ  
SHOT: 1070 G10

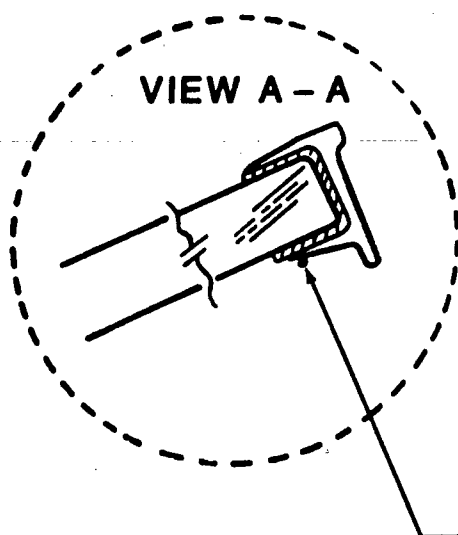
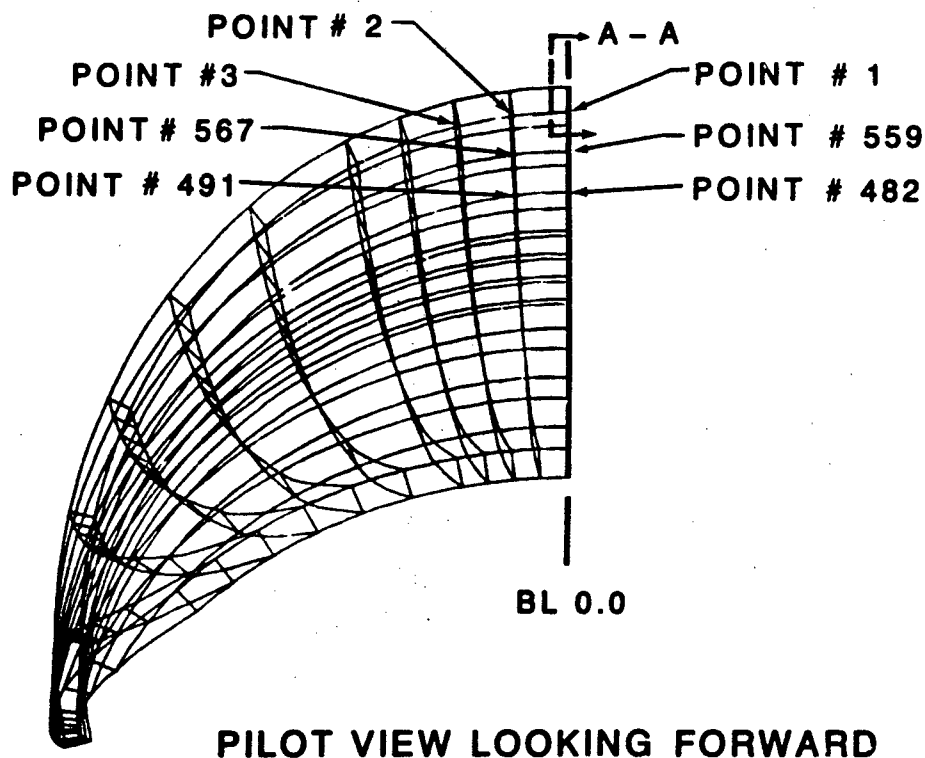
Lowpass Filter  
Low Frequency Cutoff = 0.0100MH



SCALE FACTOR = 3042.0

# APPENDIX B

## FINITE ELEMENT MODEL

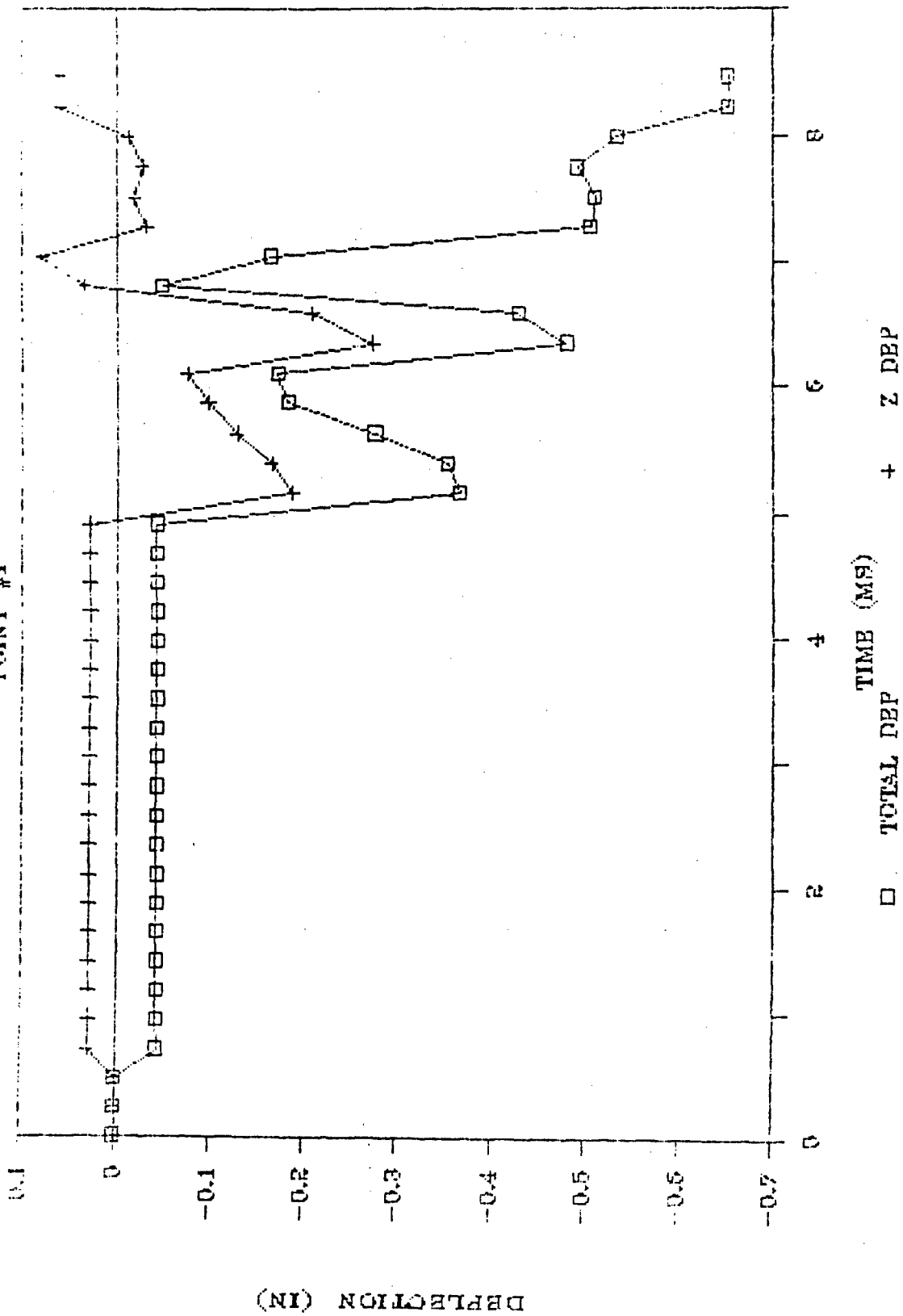


POINT	BL	FS	WL
• 1	0	281.63	166.64
• 2	3.8	281.72	166.26
• 3	7.4	282.04	165.02
559	0	277.7	164.6
567	3.7	277.8	164.2
482	0	273.1	162.1
491	3.5	273.2	161.8

• POINT LOCATED ON ARCH

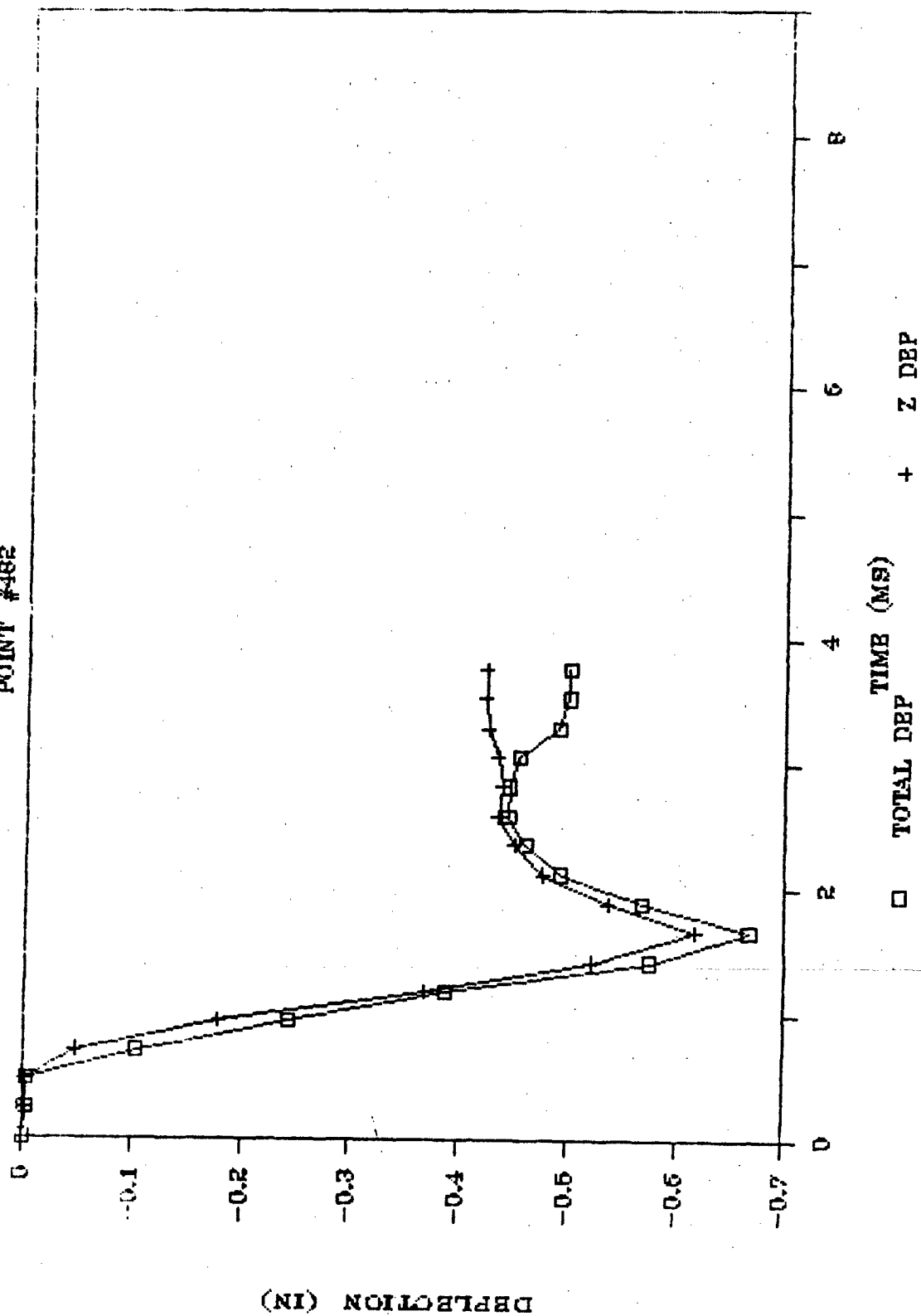
# SHOT 1068

POINT #1



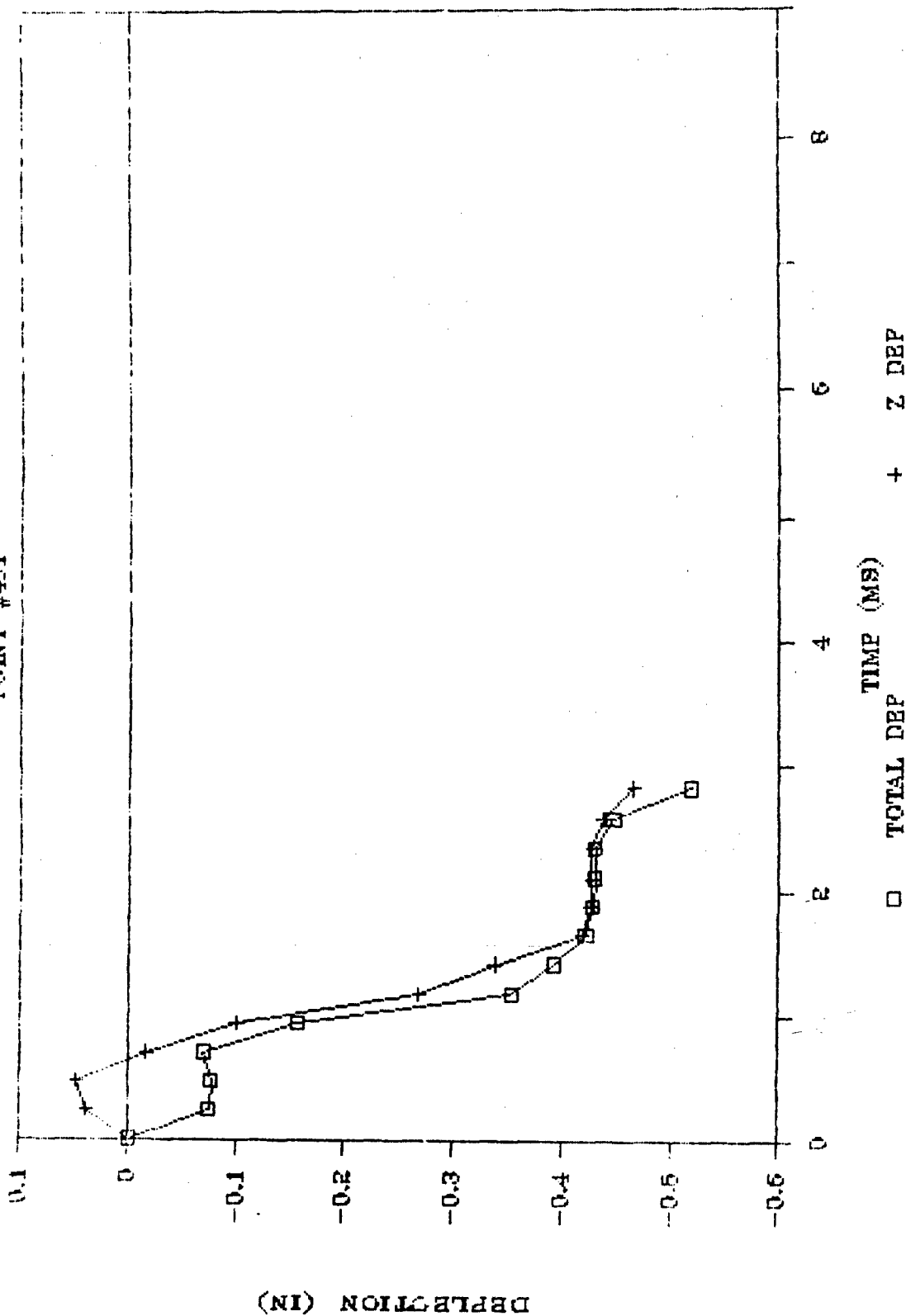
# SHOT 1068

POINT #482



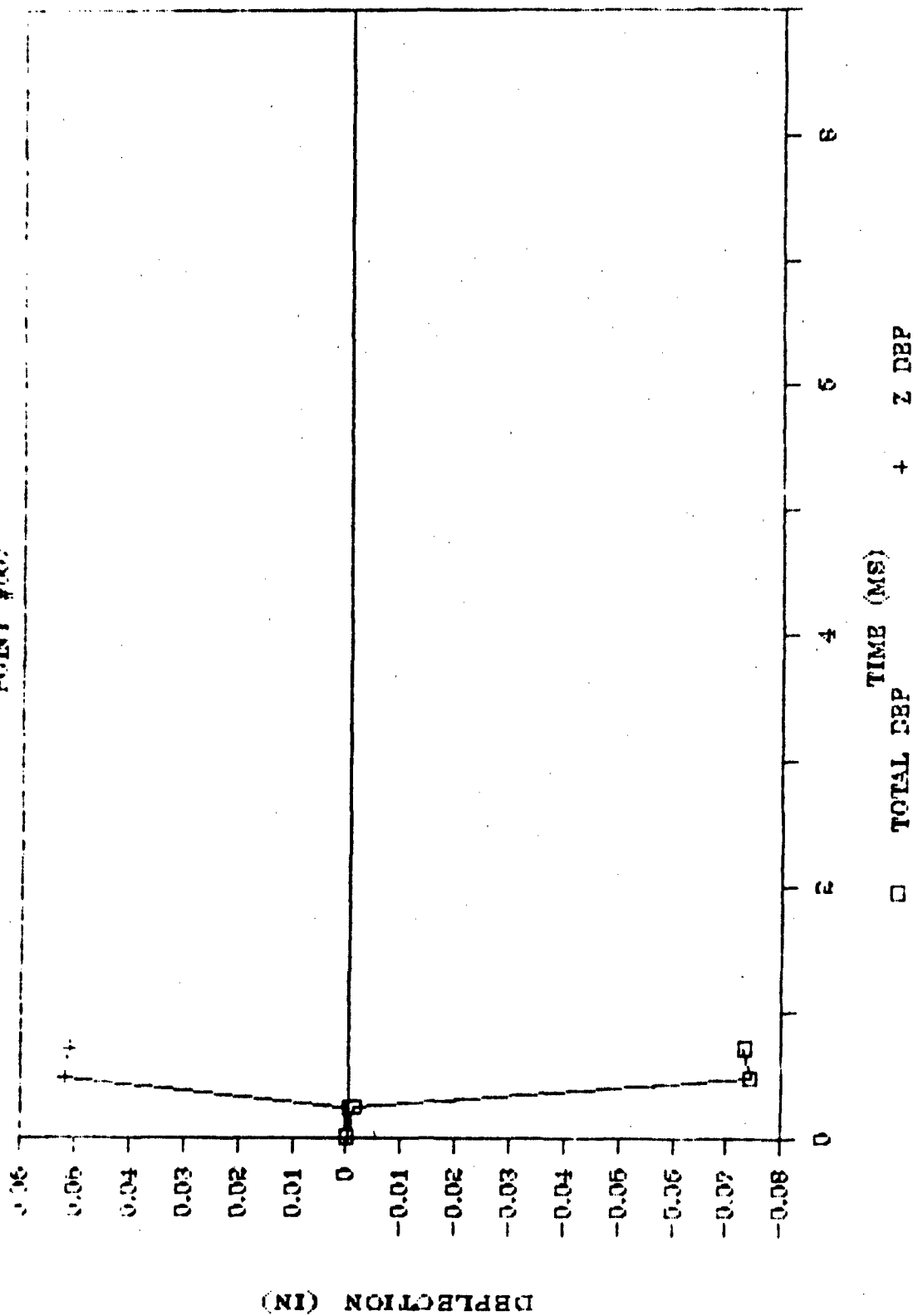
# SHOT 1068

POINT #491



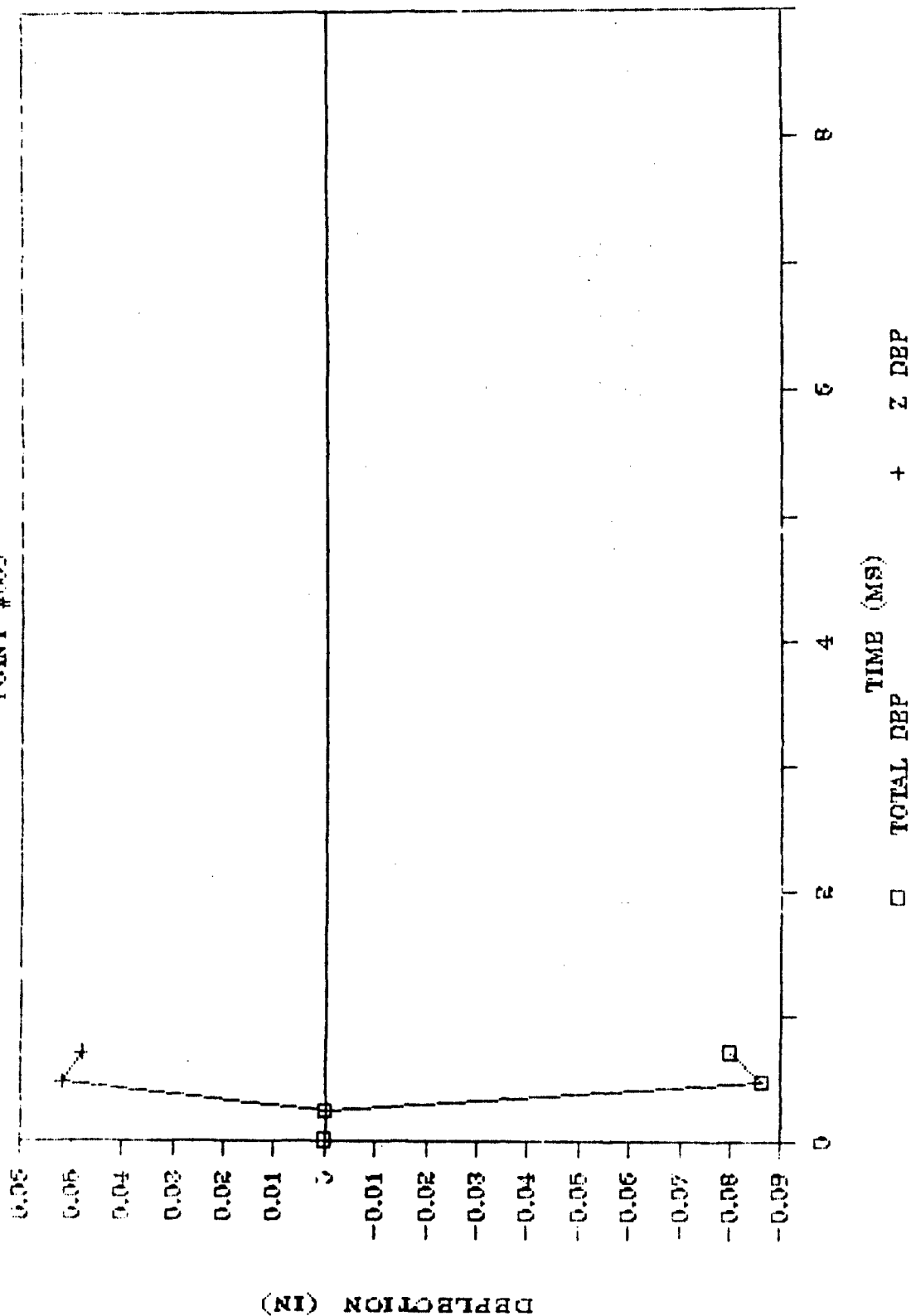
# SHOT 1068

POINT #662



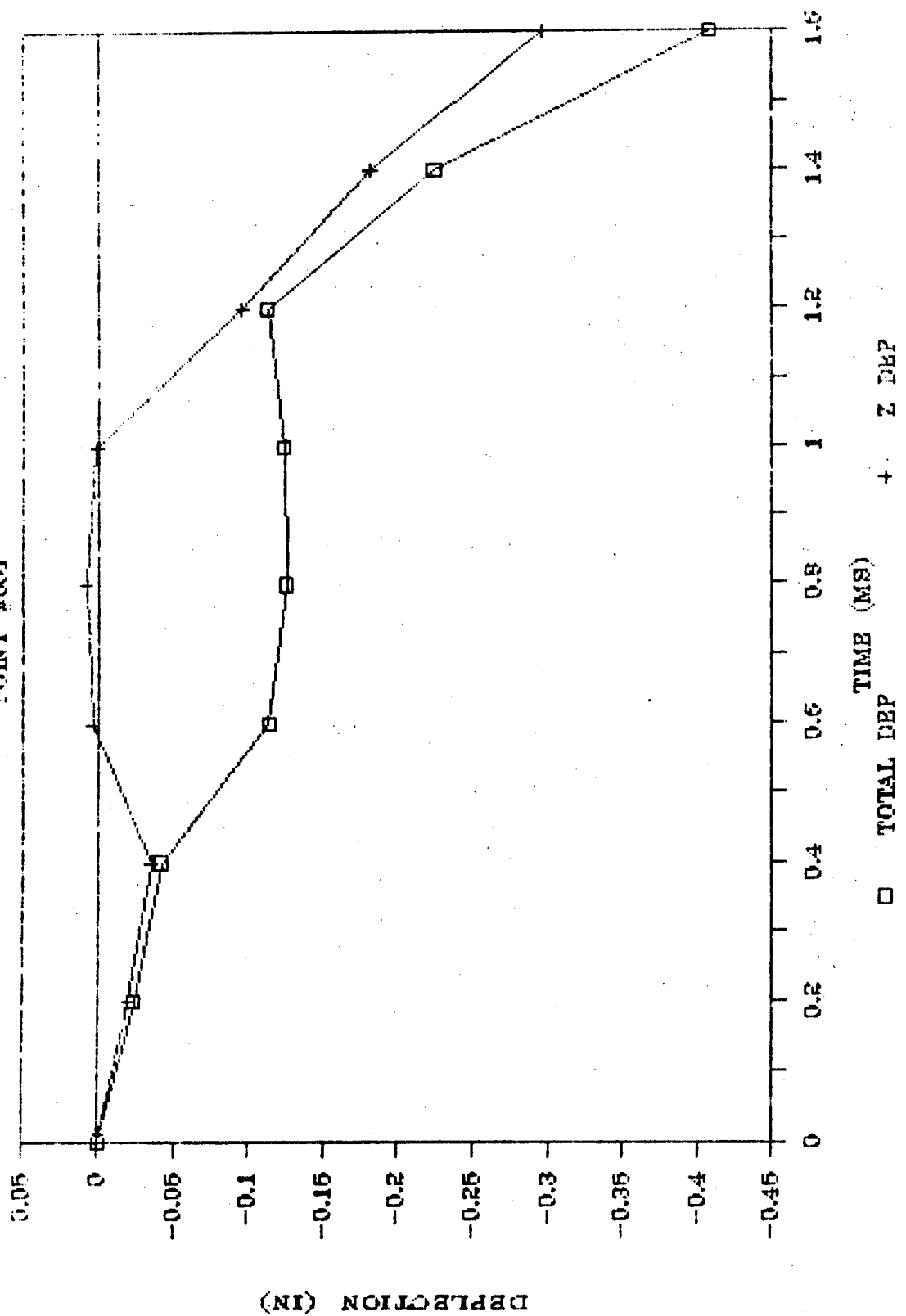
# SHOT 106B

POINT #559



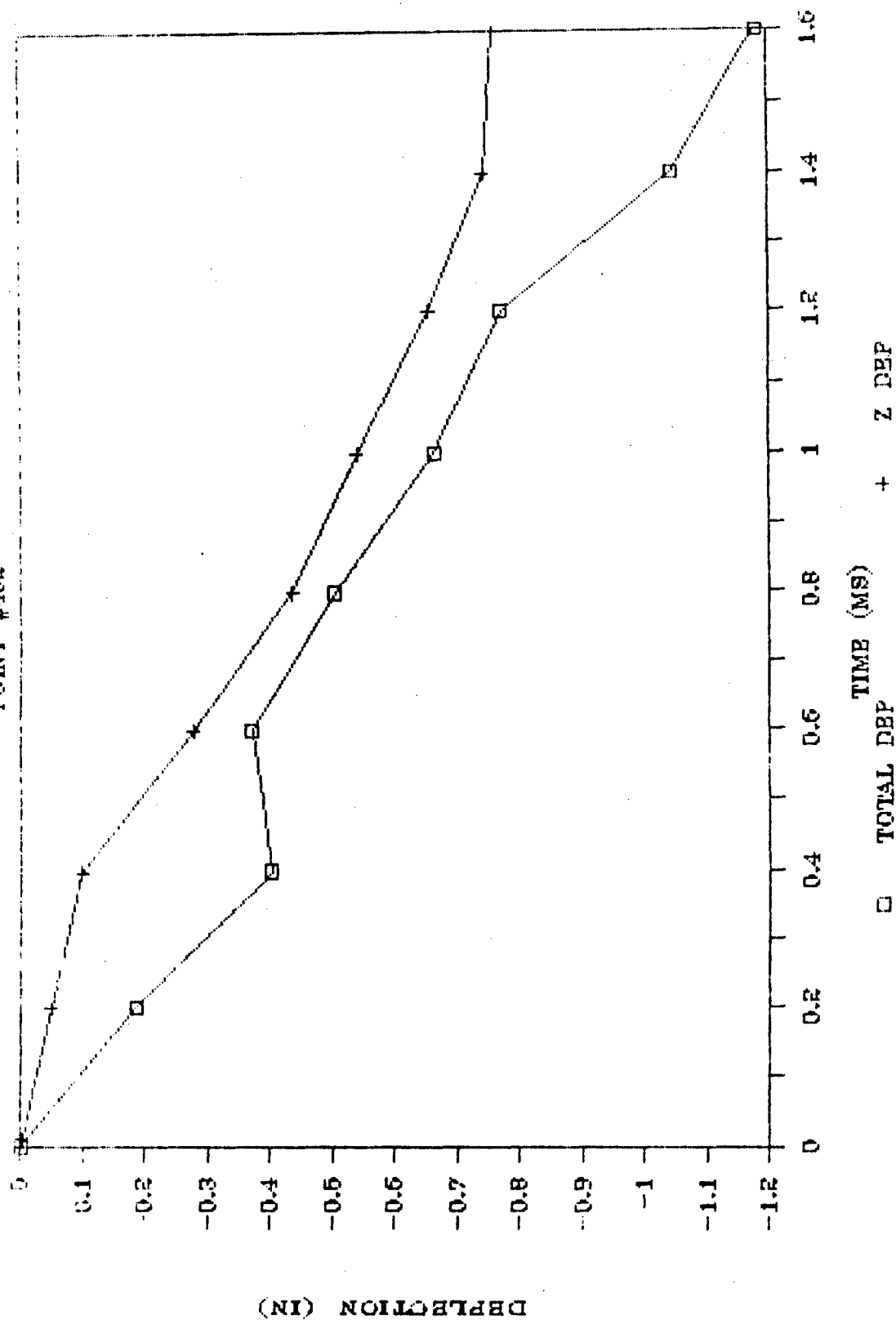
# SHOT 1069

POINT #001



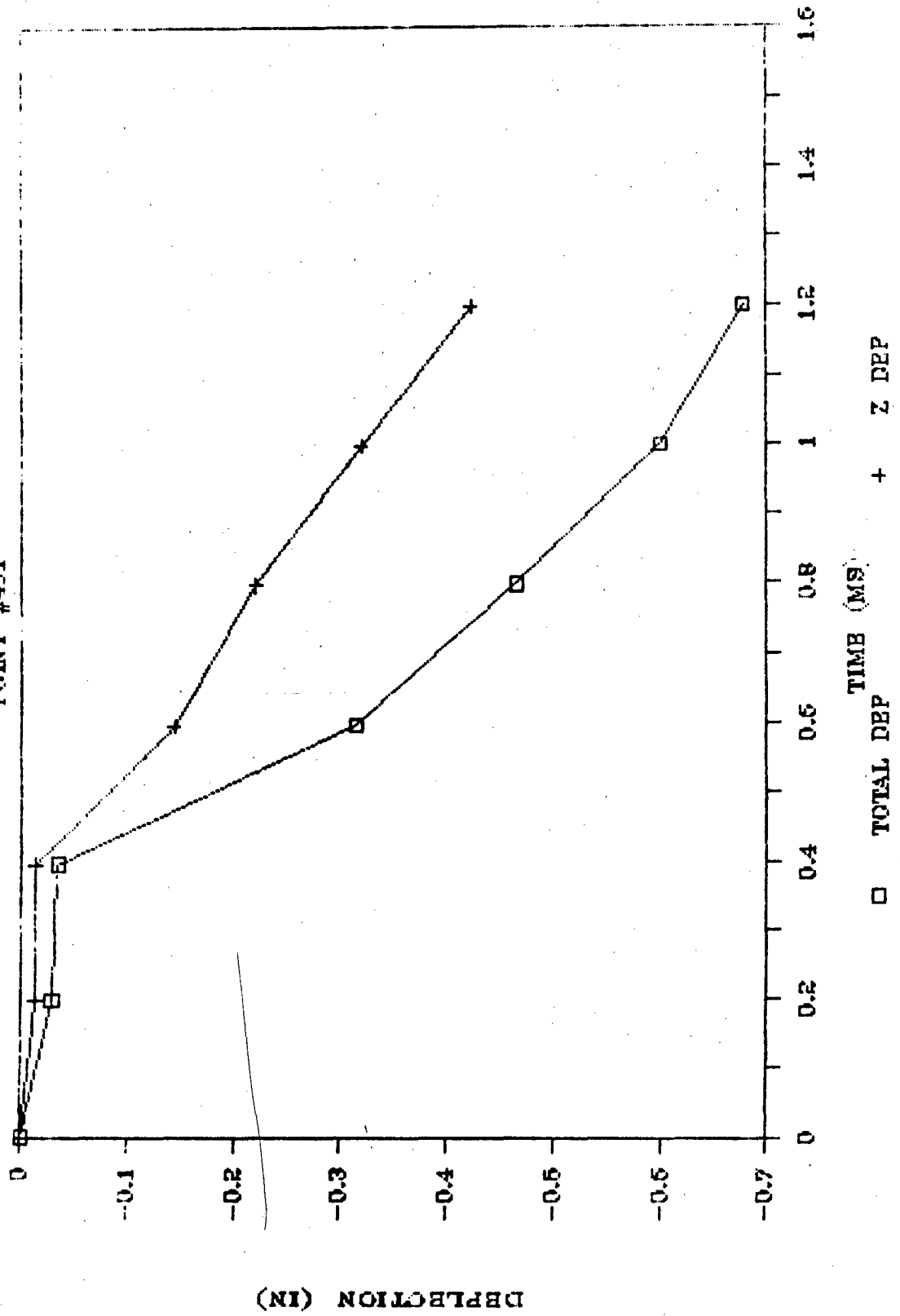
# SHOT 1069

POINT #482



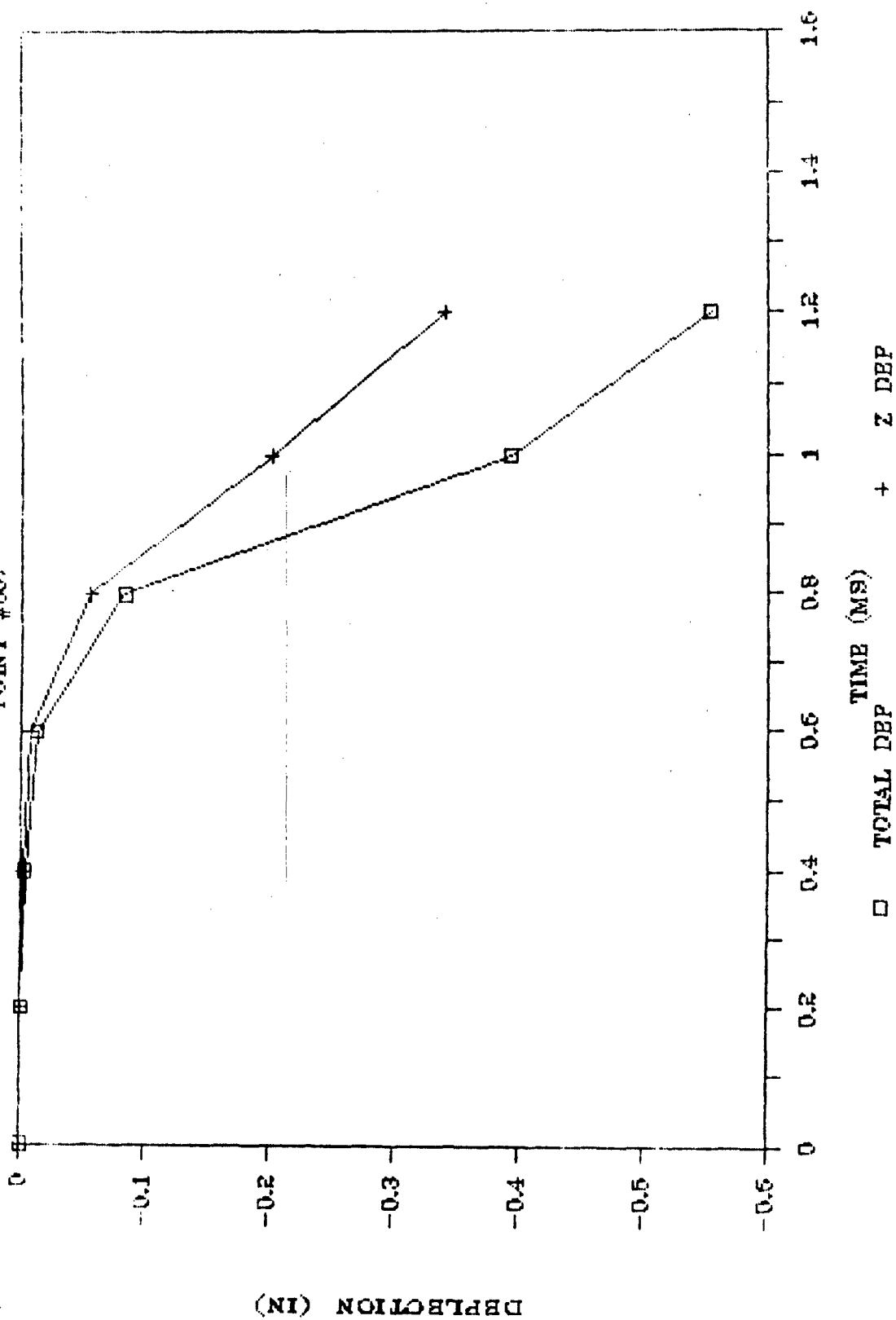
# SHOT 1069

POINT #491



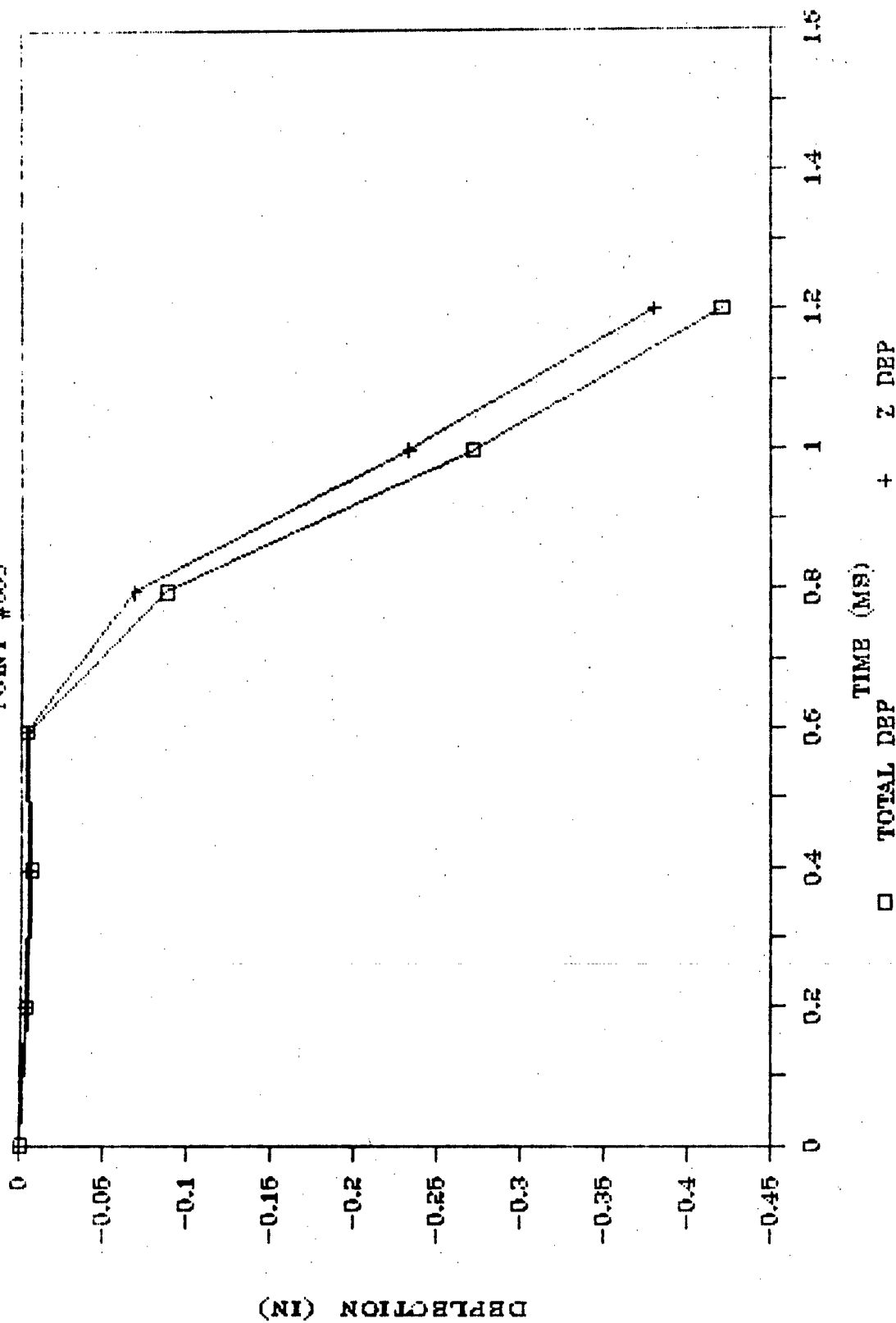
# SHOT 1069

POINT #56%



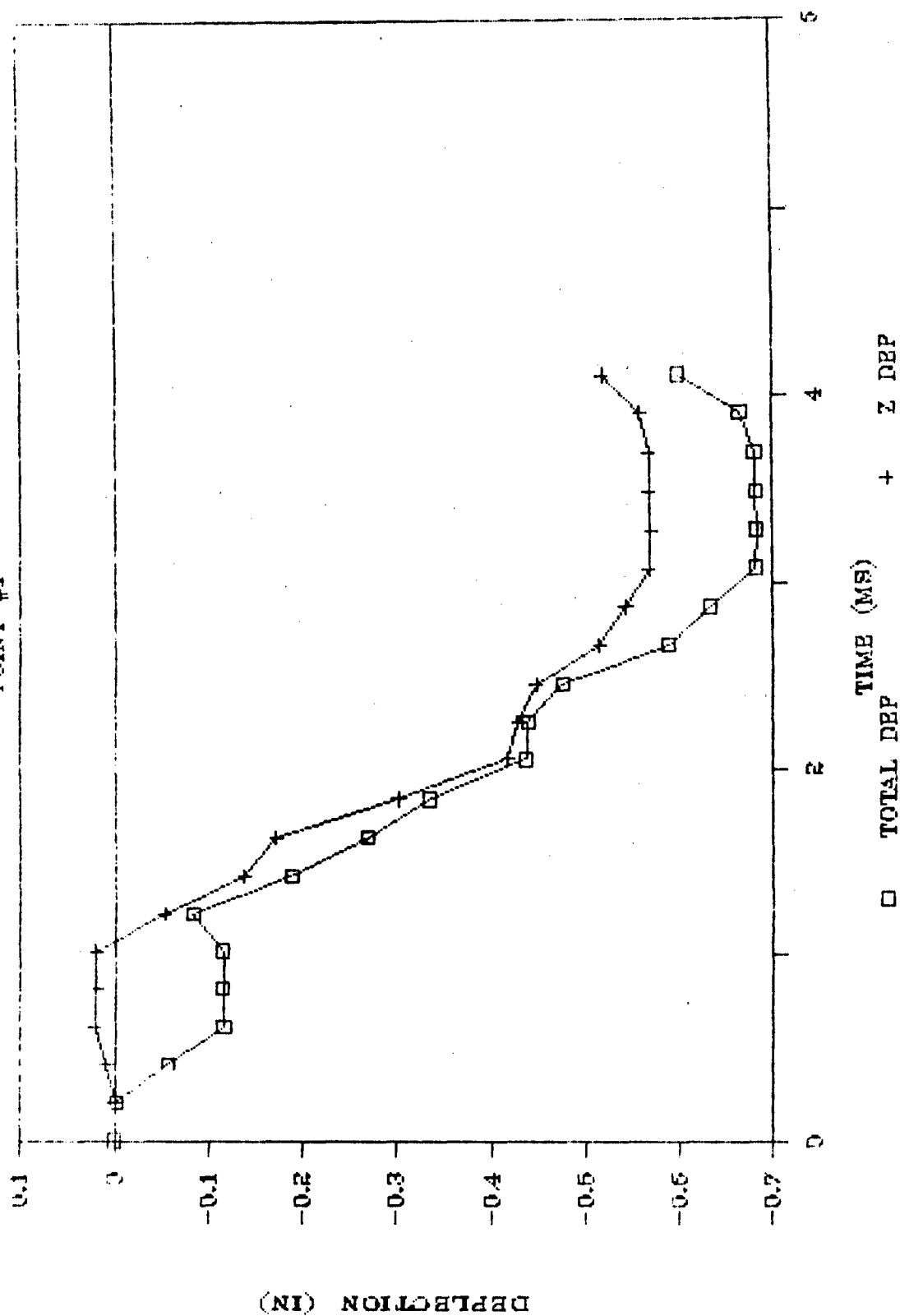
# SHOT 1069

POINT #559



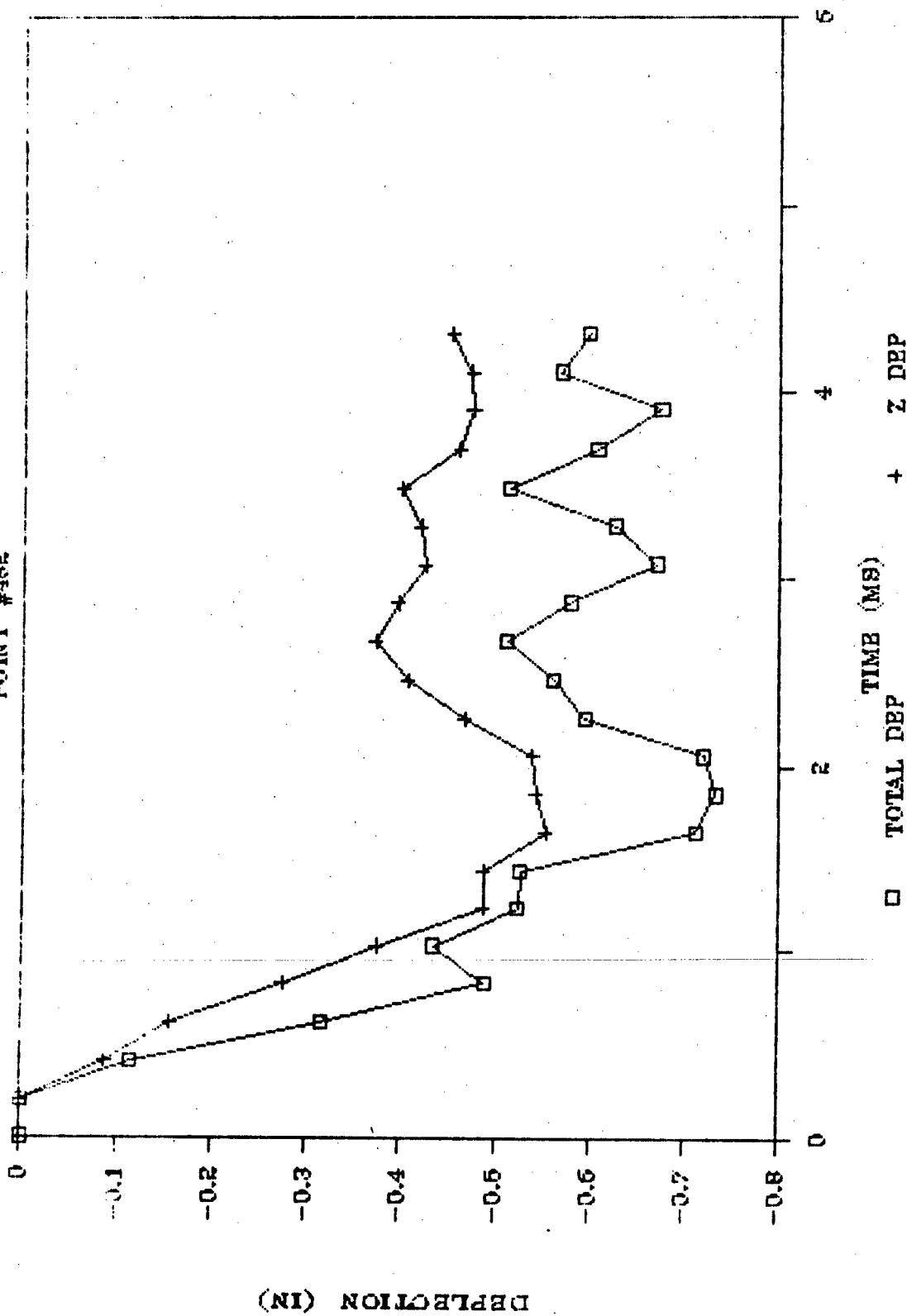
# SHOT 1070

POINT #1



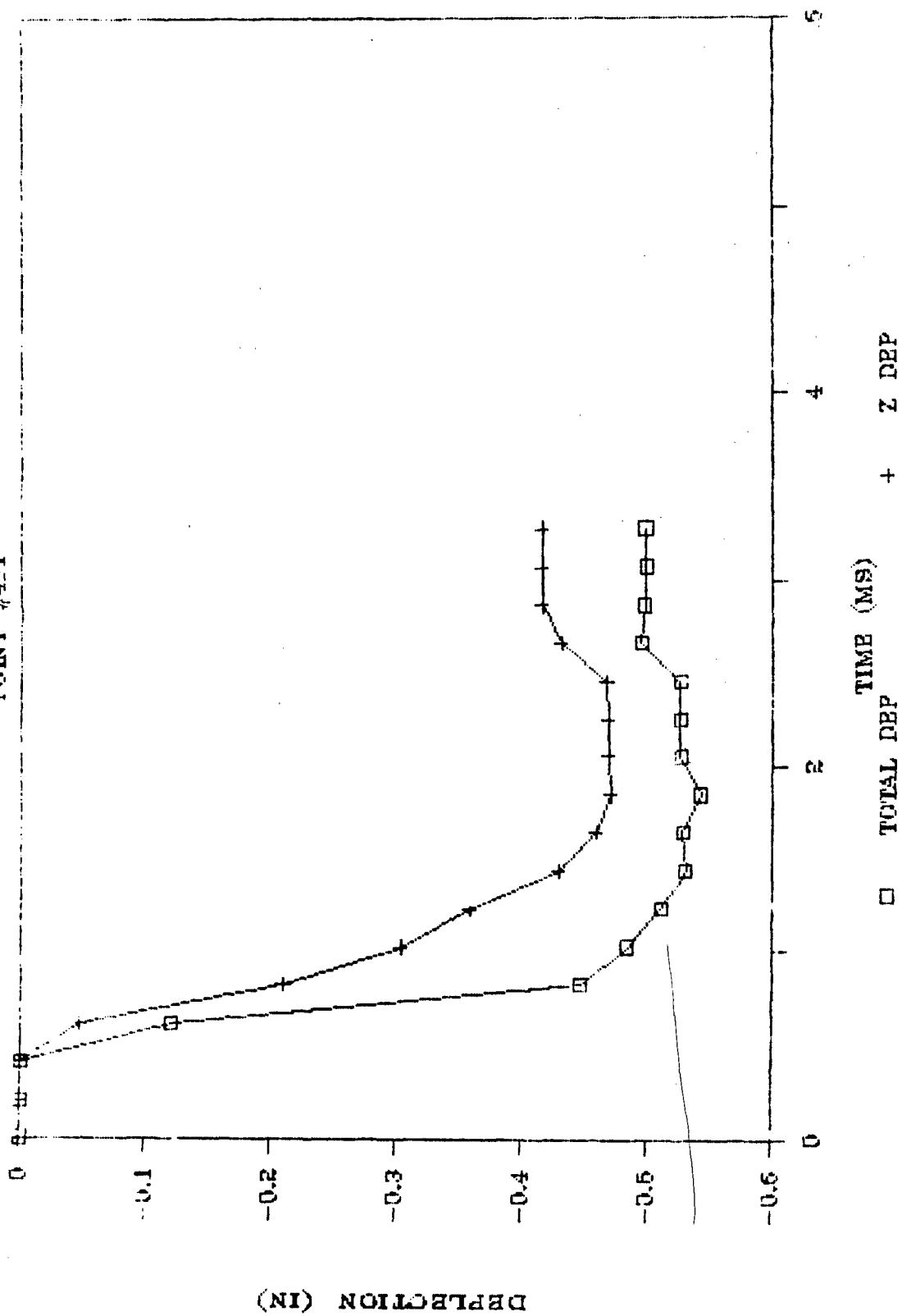
# SHOT 1070

PORT #482



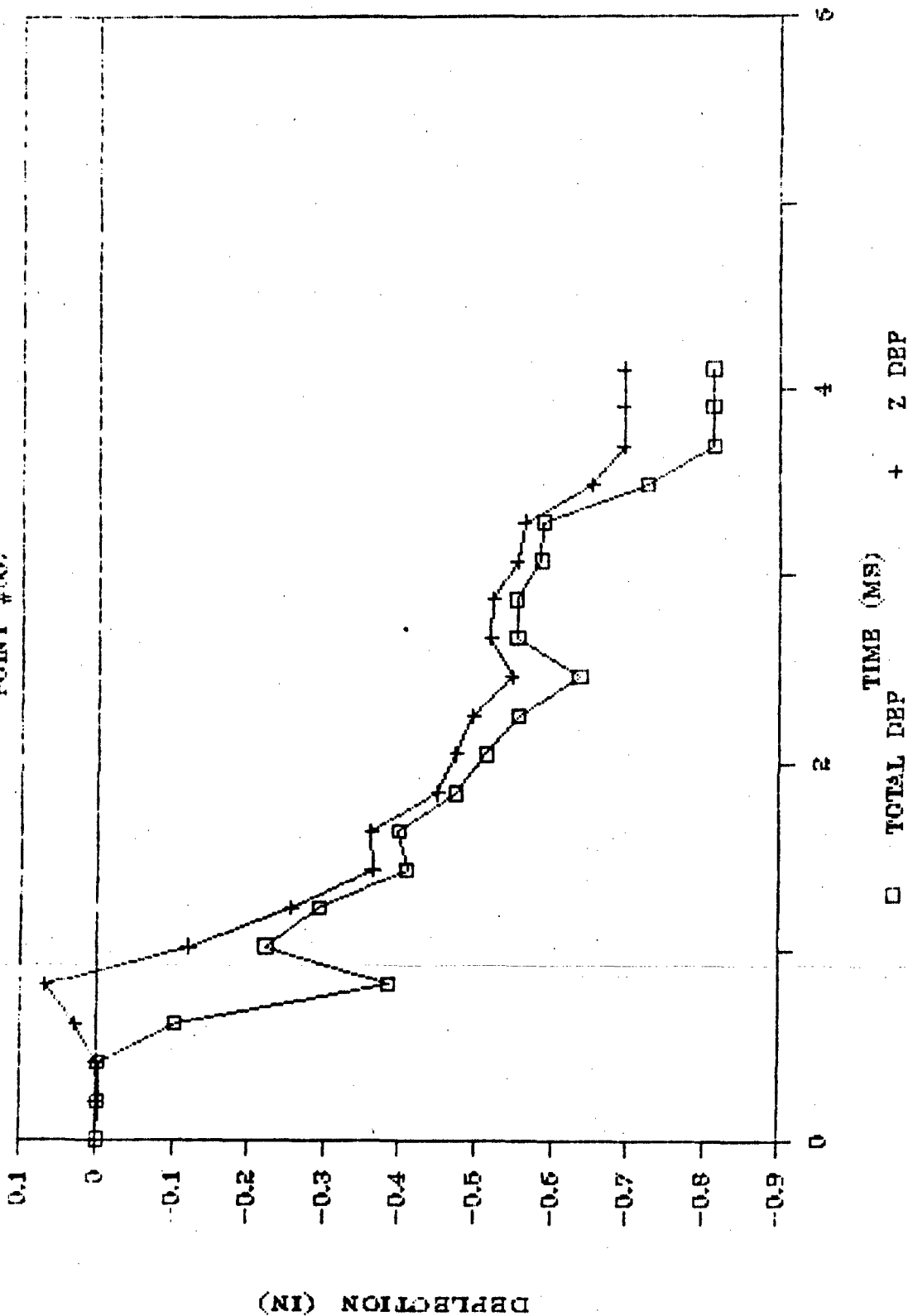
# SHOT 1070

POINT #491



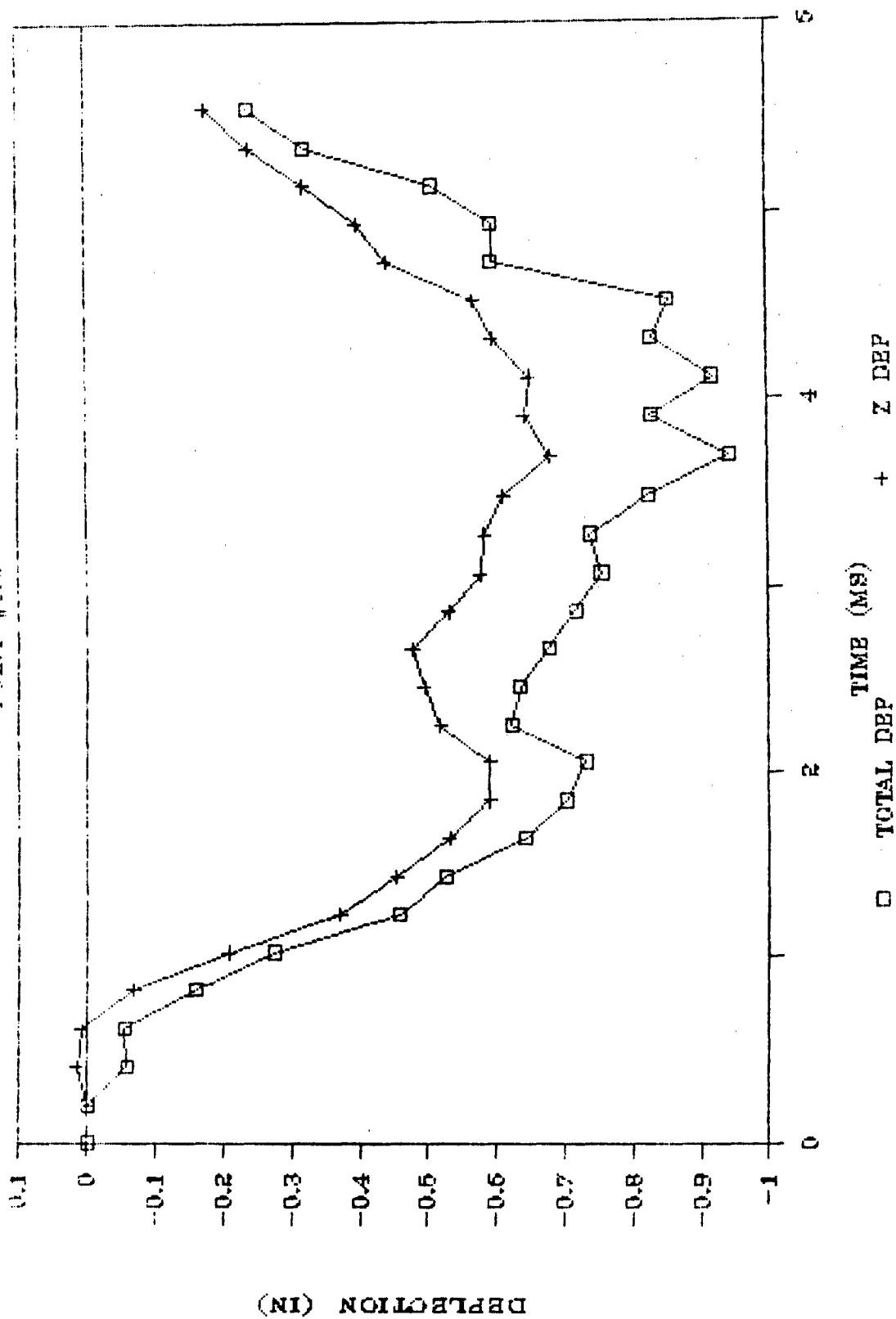
# SHOT 1070

POINT #569



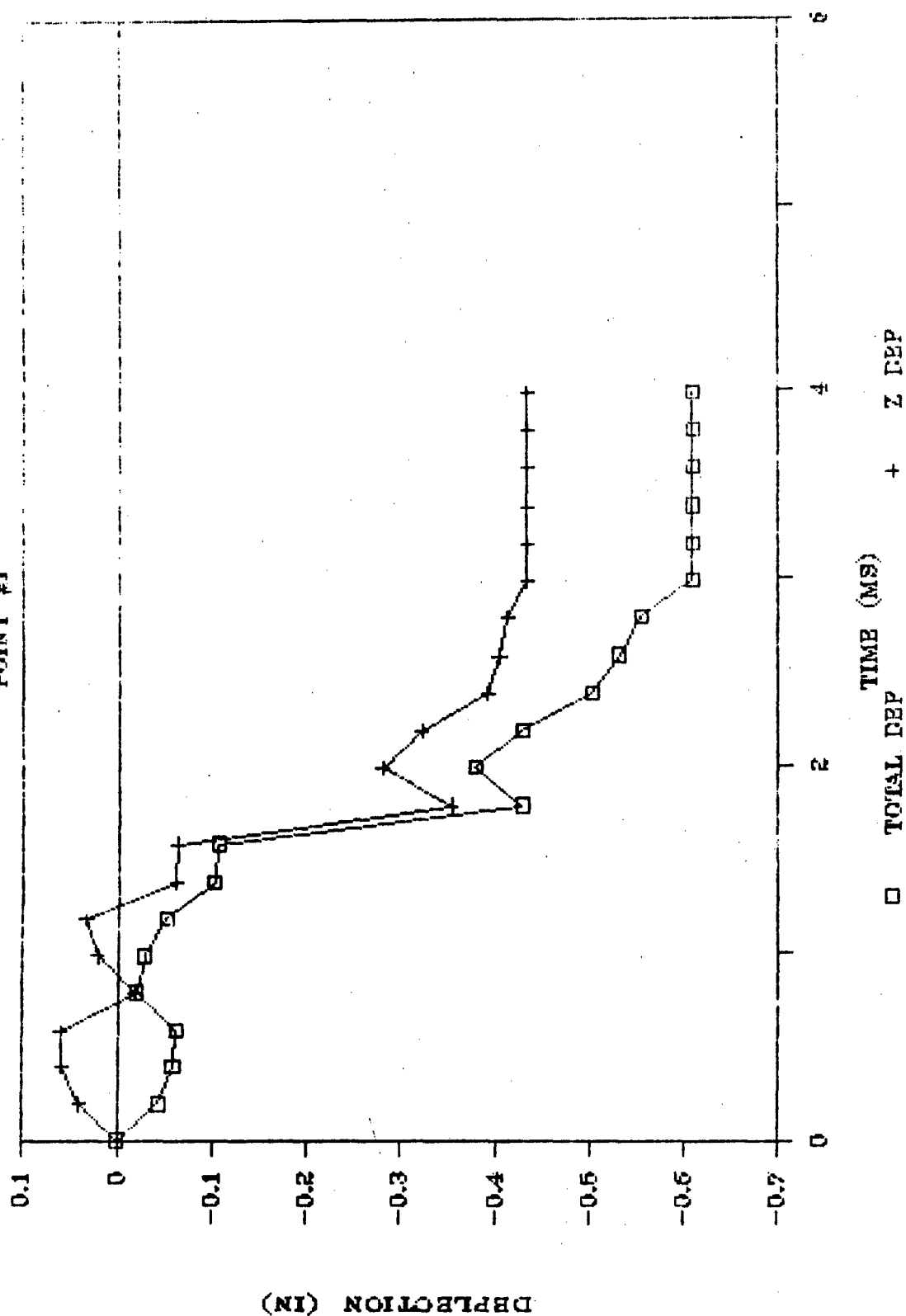
# SHOT 1070

POINT #559



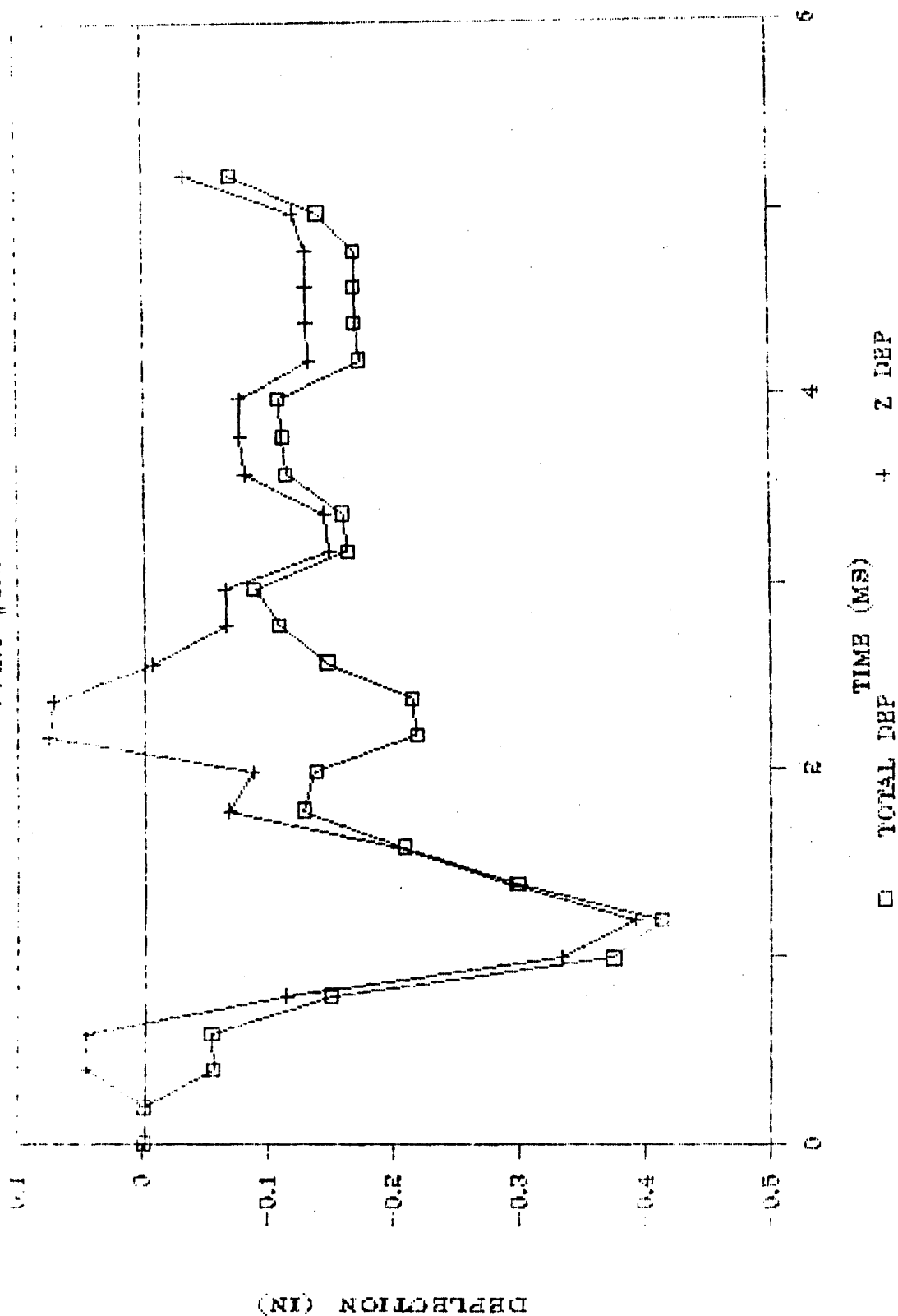
# SHOT 1082

POINT #1



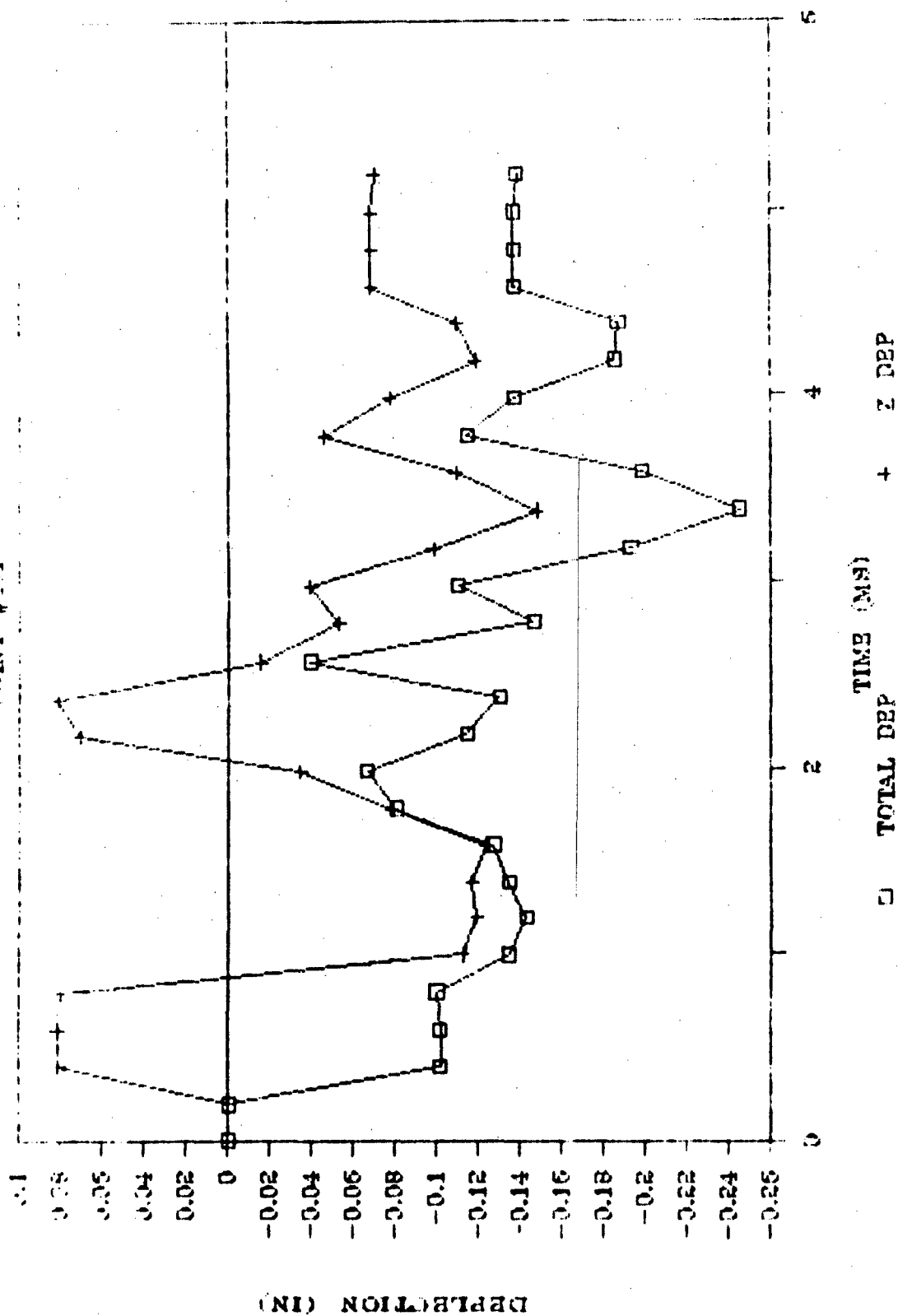
# SHOT 1082

POINT #382



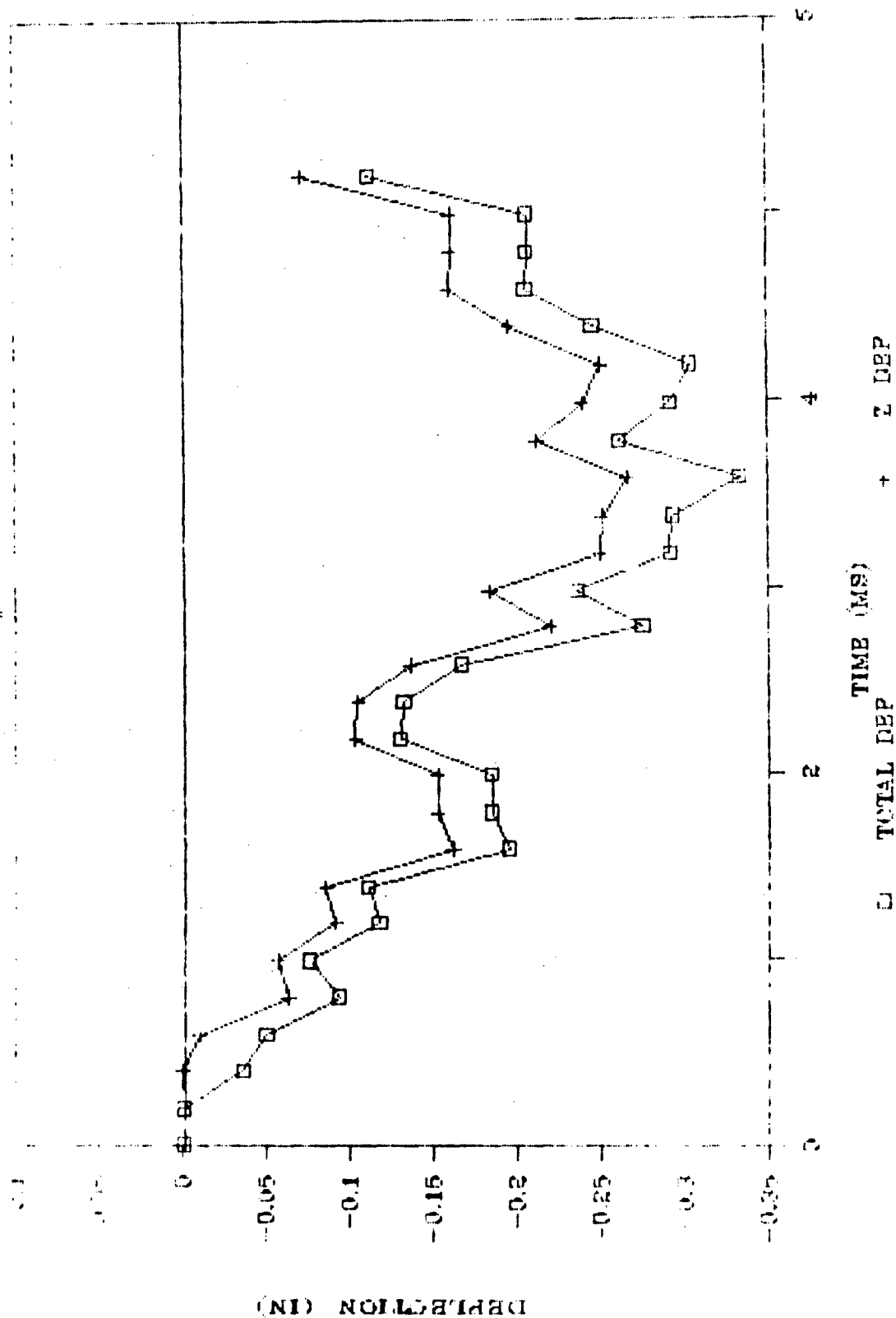
# SHOT 1082

PICNT #001



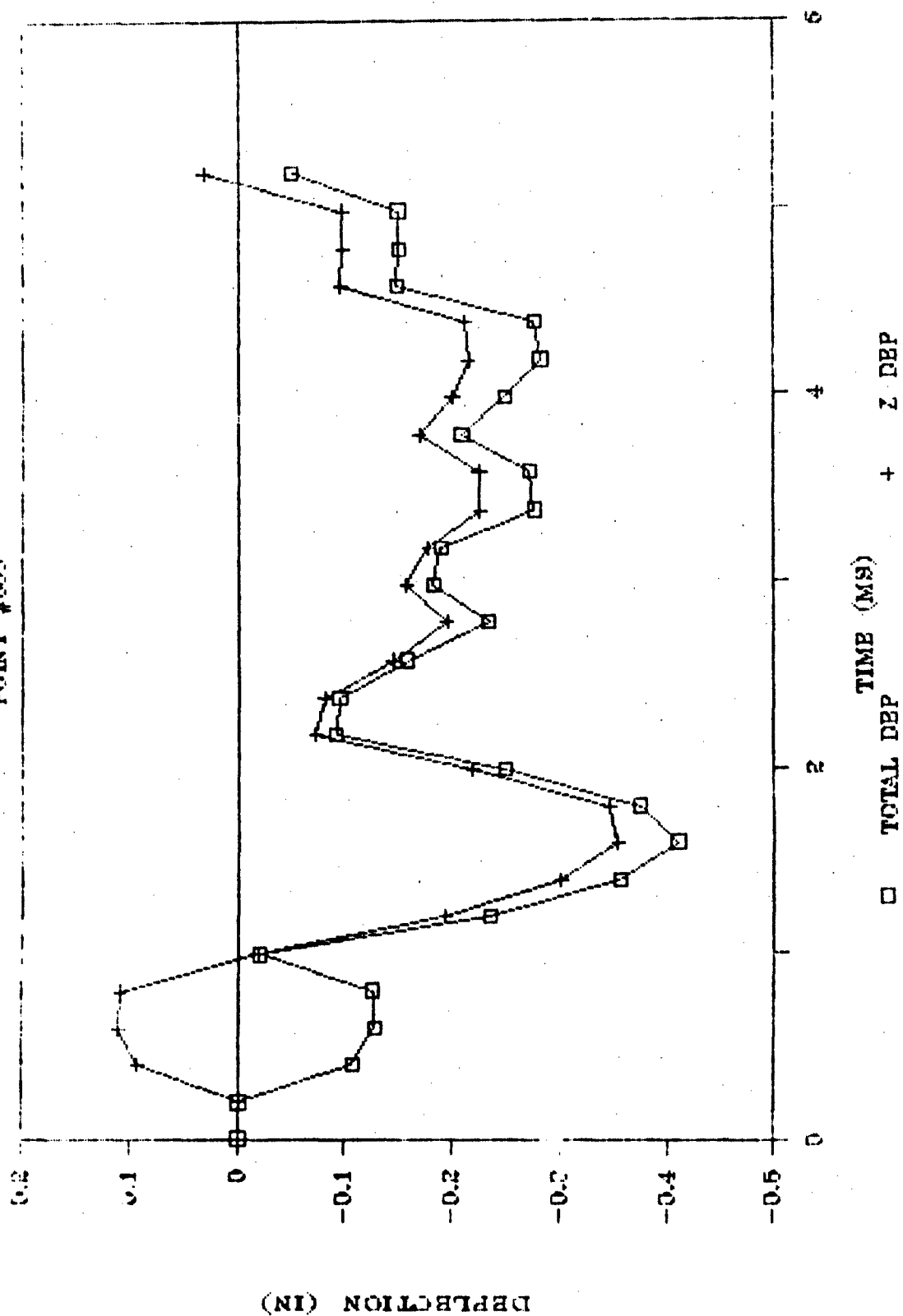
# SHOT 1082

POINT #162



# SHOT 1082

POINT #559



**END  
FILMED**

DATE:

4-93

**DTIC**